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TESTS OF OIL RECOVERY DEVICES IN BROKEN ICE FIELDS

PHASE II

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FINAL REPORT

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16. Abstract

This final report summarizes the results of tests conducted in broken ice cover with crude oil and No. 2 fuel oil of five oil spill recovery devices manufactured by Lockheed, Marco, Ocean Systems, JBF Scientific, and Oil Mop. Additional tests were conducted to determine the natural spill thickness of crude oil and No. 2 fuel oil in open water at low temperature and in broken ice cover.

The spreading tests indicated that thin oils will spread to a very thin layer whether in open water or in broken ice cover. Heavy oils in broken ice cover will achieve a natural equilibrium thickness many times greater than the open water thickness due to the partial containment of the oil by the broken ice pieces.

The oil recovery tests demonstrated that modifications made to the Lockheed and Marco devices did improve their performance when operating in broken ice cover. Ice interaction problems experienced with the Lockheed unit were eliminated through the addition of protective guards below the waterline. Tests conducted with various types of ice processing equipment attached to the Marco unit revealed performance improvements of as much as 59% in oil recovery rate, 230% in oil recovery efficiency, and 56% in throughput efficiency in comparison to the unmodified unit.

Tests conducted with the OSI, JBF, and Oil Mop units were more elementary in nature and did not incorporate modification of the devices for use in ice. Tests of the OSI and JBF units indicated that modifications would be required to adapt them for satisfactory operation in broken ice cover. Tests of the Oil Mop unit indicated that it has promise in applications involving heavier oils.

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PREFACE

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Acknowledgement and appreciation are also extended to the employees of ARCTEC, Incorporated who participated in this program. O. M. Halstad was largely responsible for the conceptual design of the laboratory testing equipment and the ice processing equipment. The construction and installation of all equipment, and the conduct of testing were under the direction of D. L. Benze, Laboratory Manager. In addition to Mr. Benze, the primary test team consisted of D. E. Abrams, Senior Technician, who was responsible for data collection and reduction, and Technicians T. Jeffrey and H. Huber. Other participants in the project included P. C. Deslauriers, J. Toeneboehn, R. Shelsby, L. Schnebelen and W. Hennessy. The entire project team is to be complimented on the excellence of their performance under very difficult working conditions.

METRIC CONVERSION FACTORS

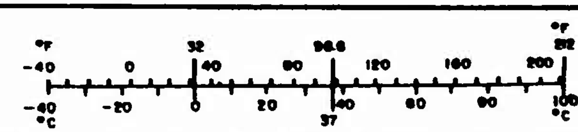
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

This is the final report of full size tests of five oil spill recovery devices, the Lockheed Clean Sweep Model R2003, the Marco Pollution Control Class I Oil Recovery System, the OSI ORS-125 Skimmer, the JBF DIP 1001, and the Oil Mop Mark II-4EP operating in a simulated Arctic environment incorporating below freezing temperatures and ice infested waters. This work comprises the second phase of a two phase program directed towards evaluating the applicability of existing oil spill recovery equipment for use in recovering oil spilled in broken ice fields of moderate ice piece size. The Phase I program demonstrated that the Lockheed and Marco devices could successfully recover crude oil and No. 2 fuel oil spilled in a broken ice field of moderate ice piece size with minor hardware modifications and the use of proper operating procedures. The Phase I program also resulted in the identification of further modifications to the units intended to enhance their oil recovery performance in broken ice fields. The Phase II tests described in this report were conducted in broken fresh water ice with No. 2 fuel oil and a crude oil selected to closely match the properties of Prudhoe Bay crude oil. The tests conducted with the Lockheed and Marco devices were directed toward the evaluation of the modifications identified in Phase I intended to improve the performance of the devices when operating in broken ice cover. In addition, the variation in oil recovery performance with variation in forward speed and drum rotational speed for the Lockheed unit, and forward speed and belt speed for the Marco units was determined. The tests conducted with the OSI, JBF, and Oil Mop units were more elementary in nature, intended to generally evaluate the suitability of these unmodified devices for recovering oil spilled in broken ice fields of moderate ice piece size. Tests were also conducted to determine the natural equilibrium spill thickness of crude oil and No. 2 fuel oil in open water at low temperature and in broken ice cover.

The spreading tests indicated that thin oils will spread to a very thin layer, whether in open water or in broken ice cover. Heavy oils in broken ice cover will, however, achieve a natural equilibrium thickness many times greater than the open water thickness due to the partial containment of the oil by the broken ice pieces.

The tests demonstrated that the modifications made to the Lockheed and Marco devices did improve their performance when operating in broken ice cover. Problems experienced in Phase I while operating the Lockheed unit in broken ice consisting of the bending of vanes by ice impact and ice jamming between the stationary frame and rotating drum of the unit were eliminated through the addition of protective guards below the waterline. Problems experienced in Phase I in removing

the oil/ice/water mixture from the small sump of the Lockheed unit were eliminated with the use of a custom fabricated screw pump. Tests also indicated that the oil recovery performance of the Lockheed unit could be improved through a reduction in the number of vanes installed on the unit.

Tests conducted with various types of ice processing equipment attached to the Marco unit revealed performance improvements of as much as 59% in oil recovery rate, 230% in oil recovery efficiency, and 56% in throughput efficiency in comparison to the performance of the unmodified unit. The success of these ice processors indicates that with the development of effective ice processing equipment, the selection of an oil recovery device for application in ice infested waters can be made on the basis of open water performance, assuming that proper provision has been made for any other unusual environmental conditions.

Tests conducted with the OSI Skimmer and the JBF DIP indicated that both units are not well adapted to operations in broken ice fields in their off-the-shelf condition. Both units could, however, be adapted for successful operations in broken ice fields through the addition of suitable ice processing equipment. Tests conducted with the Oil Mop unit in ice infested waters indicated that the unit has promise in applications involving heavier oils.

INTRODUCTION

This final report summarizes the results of full size tests of five oil spill recovery devices operating in a simulated Arctic environment incorporating below freezing temperatures and ice infested waters. These tests were conducted in the Ice Model Basin of ARCTEC, Incorporated in Columbia, Maryland, during October and November of 1975.

The present worldwide energy situation has focused attention on the Arctic as a major source of oil. Petroleum exploration, production and transportation activities in the Arctic will result in an increased potential for oil spills in ice infested waters. The U.S. Coast Guard has the responsibility for promulgation and enforcement of regulations concerning oil pollution of U.S. waters. This responsibility includes Alaskan coastal and offshore waters, coastal rivers subject to tidal influence, ports, the contiguous zones, and the high seas where there exists a threat to U.S. waters, shoreface, or shelf bottom.

A major test of available oil spill recovery equipment was conducted by the U.S. Coast Guard at Homer, Alaska, during November and December of 1973. The purpose of the test program was to evaluate existing off-the-shelf oil containment and recovery devices in a freezing or near freezing ice/water environment, and to determine the effect of cold temperatures and ice on them. Oil was not spilled for these tests for logistic as well as environmental reasons. The tests showed that of the six recovery devices tested, two devices, the Lockheed disc drum and the Marco oleophilic belt, held the most promise for successfully recovering oil from an oil/ice/water environment.

To further evaluate the ability of existing oil spill recovery equipment to operate successfully in broken ice fields, the Coast Guard outlined a two phase program having as its general objective the determination of the oil recovery capability of selected existing oil spill recovery equipment in an oil/water/ice environment, and the evaluation of modifications which could improve their recovery performance in this environment. Phase I testing was conducted by ARCTEC, Incorporated during March and April of 1975. The results of the Phase I program are presented in report CG-D-130-75, prepared for the United States Coast Guard Office of Research and Development (Reference 1). The two oil spill recovery devices selected for testing in Phase I were the Lockheed Clean Sweep Model R2003 and the Marco Pollution Control Class I Oil Recovery System. Tests were conducted with both devices in broken fresh water ice and broken salt water ice, with No. 2 fuel oil and a crude oil selected to closely match the

properties of Prudhoe Bay crude oil, in two oil thicknesses and at temperatures of +25°F and +15°F. The Phase I test program indicated that with minor hardware modifications and the use of proper operating procedures, both devices could successfully recover crude oil and No. 2 fuel oil spilled in a broken ice field of moderate ice piece size. The Phase II test program, the subject of this report, included testing of the same two oil spill recovery devices under different operating conditions and with modifications intended to improve the oil recovery performance of the devices when operating in ice-infested waters. Additional tests were conducted with the Lockheed and Marco units to determine the variation in oil recovery performance due to variation in the speed of advance of the unit, the drum speed of the Lockheed unit, and the belt speed of the Marco unit. The Phase II program also included testing of the Lockheed and Marco devices at low temperatures in open water without ice; basic testing of three additional oil spill recovery units in ice infested waters, namely, the JBF DIP, the OSI Skimmer, and the Oil Mop; and testing to determine the spreading characteristics of No. 2 fuel oil and crude oil at low temperatures in open water and in ice infested waters. All of the oil spill recovery devices tested in the Phase II program are described in Appendix A. The objectives of the Phase II test program were established as follows:

1. Modify the Lockheed and Marco oil spill recovery units tested in the Phase I program to improve their performance in ice infested waters and conduct tests to verify the improvement.

2. Through additional testing of the modified Lockheed and Marco units, evaluate the oil recovery performance variation of each unit with variation in speed of advance and drum speed or belt speed.

3. Determine the equilibrium oil slick thickness for No. 2 fuel oil and for crude oil under the test conditions in both open water and in ice infested water.

4. Determine the oil spill recovery performance of the Lockheed and Marco units operating at low temperatures in open water.

5. Perform basic testing of three additional oil spill recovery devices at low temperatures in ice infested waters. These additional oil spill recovery devices are the JBF DIP, the OSI Skimmer and the Oil Mop.

In order to meet these program objectives, a test program consisting of fifty tests was developed as shown in Table 1 and described in the project Test Plan (Reference 2). As originally developed, the fifty test program included ten tests designed to evaluate modifications made to the Lockheed and Marco units, eighteen

TABLE 1. SUMMARY OF PLANNED TEST PROGRAM

Basin Day	Test Numbers	Devices	Type of Test	Oil Type	Oil Thickness	Notes
1-5	-	-	-	-	-	Preparations and installation.
6	1,2	-	Spreading	C	Variable	Two 12'x12' areas, one open water, one with 95% broken ice.
7	3,4	L, M	Open Water	C	1/2"	Unmodified devices, for Phase I comparison; T_a = 32F. After test spread oil.
8	5,6	L, M	Open Water	C	Min.	Unmodified devices, for Phase II comparison; T_a = 32F. After test add ice.
9	7,8	L, M	Modification	C	Min.	Lockheed unmodified; Marco with static processor.
10	9,10	L, M	Modification	C	Min.	Lockheed with 16 vanes; Marco with free-wheeling processor.
11	11,12	L, M	Modification	C	Min.	Lockheed with 8 vanes; Marco with driven processor.
12	13,14	L, M	Performance	C	Min.	8 rpm drum, 4 fps belt, 1.00 fps advance.
13	15,16	L, M	Performance	C	Min.	8 rpm drum, 4 fps belt, 1.50 or 0.25 fps advance.
14	17,18	L, M	Performance	C	Min.	3 rpm drum, 1 fps belt, advance selected on above.

TABLE 1. SUMMARY OF PLANNED TEST PROGRAM (CONT'D)

Basin Day	Test Numbers	Devices	Type of Test	Oil Type	Oil Thickness	Notes
15	19,20	L, M	Performance	C	Min.	13 rpm drum, 2.5 fps belt, advance selected on above.
16	-	-	-	-	-	Install OSI and JBF devices.
17	21-23	JBF,OSI	Other Units	C	Min.	JBF towed at 0.5 fps, JBF self-propelled, OSI towed at 1.35 fps.
18	24,25	OM	Other Units	C	Min.,1/2"	Min. thickness in one half of basin, 1/2" in other half. After test spread oil.
19	26,27	L, M	Modification	C	1/2"	For comparison with Phase I results.
20,21	-	-	-	-	-	Changeover from crude to #2.
22	28,29	-	Spreading	#2	Variable	Two 12'x12' areas, one open water, one with 95% broken ice. After test spread oil.
23	30,31	L, M	Open Water	#2	1/2"	Unmodified devices for Phase I comparison; T_a = 32F.
24	32,33	L, M	Open Water	#2	Min.	Unmodified devices, for Phase II comparison; T_a = 32F. After test add ice.
25	34-36	JBF,OSI	Other Units	#2	Min.	JBF towed at 0.5 fps, JBF self-propelled, OSI towed at 1.35 fps.

TABLE 1. SUMMARY OF PLANNED TEST PROGRAM (CONT'D)

Basin Day	Test Numbers	Devices	Type of Test	Oil Type	Oil Thickness	Notes
26	37,38	L, M	Performance	#2	Min.	8 rpm drum, 4 fps belt, 0.50 fps advance.
27	39,40	L, M	Performance	#2	Min.	8 rpm drum, 4 fps belt, 1.00 fps advance.
28	41,42	L, M	Performance	#2	Min.	8 rpm drum, 4 fps belt, 1.50 or 0.25 fps advance.
29	43,44	L, M	Performance	#2	Min.	3 rpm drum, 1 fps belt, advance selected on above.
30	45,46	L, M	Performance	#2	Min.	13 rpm drum, 2.5 fps belt, advance selected on above.
31	47,48	L, M	Modification	#2	1/2"	For comparison with Phase I results.
32	49,50	OM	Other Units	#2	Min.,1/2"	Min. thickness in one half of basin, 1/2" in other half.

tests designed to determine the performance variation of the units in ice infested waters, four tests to determine the equilibrium spreading thickness of crude oil and No. 2 fuel oil in open water and in a broken ice field, eight tests to determine the performance of the Lockheed and Marco units in open water at low temperatures, and ten tests to evaluate in an elementary way the performance of three additional oil spill recovery devices in ice infested waters. While the planned test sequence served as a valuable guide throughout the test program, as is generally the case in development testing, modifications were made to the testing sequence as the program developed to more efficiently complete the test program and to allow time for further hardware modifications as the test program proceeded. Table 2 is a chronological summary of the Phase II test program as it was actually conducted. Occasional missing numbers in the test number sequence identify tests which were dropped due to operational problems or suspicious data and rerun using a new test number. The large block of tests between 31 and 45 comprise the tests of a separate but related program which will be separately reported.

Two sets of parameters that were varied in the Phase I test program were held constant throughout the Phase II test program. In both cases, the decision was made to hold these parameters constant in the Phase II program because, although the Phase I testing indicated that there was some variation in the performance of the oil spill recovery units due to variation in these parameters, the variation in performance was not sufficient to materially change the evaluation of the suitability of the devices for use in broken ice cover. The parameters involved are the type of ice and the air temperature. In the Phase I test program, tests were conducted with both fresh water ice and salt water ice, while in Phase II fresh water was used exclusively throughout the program. Similarly, in Phase I, testing was conducted with air temperatures of +25°F and +15°F, while the Phase II program was conducted with air temperatures in the +25°F to +28°F range, the objective being to hold the air temperature at that value at which the broken ice cover neither melts to a significant extent, or tends to freeze into a unified mass of ice. The fresh water ice obtained from a commercial ice house in 44 x 22 x 10-1/2 inch blocks was randomly broken up to provide a range of ice piece size from fine mush, simulating salt water ice mush, to a maximum block size of 22 x 22 x 10-1/2 inches. The open water recovery tests and the spreading tests were conducted with the room air temperature maintained at +32°F so as to preclude the formation of ice prior to, or during, these tests.

As was the case in the Phase I test program, it was desired to conduct the crude oil tests with Prudhoe Bay crude, however, the cost of transporting Prudhoe Bay crude to the laboratory was shown to be prohibitive in Phase I. In the Phase I program, a substitute

TABLE 2. CHRONOLOGICAL SUMMARY OF TEST PROGRAM

Date (1975)	Test Number	Device	Type of Test	Oil Type	Thickness of Oil cm	Nom. Forward Speed fps	Nom. Belt or Drum Speed fps or rpm	Other Nominal Test Conditions
10/1	-	-	Spreading	C	Variable	-	-	In broken ice cover.
10/2	-	-	Spreading	C	Variable	-	-	In open water.
10/3	1	Marco	Open Water	C	1.27	0.5	4	Air temperature = water temperature = 32°F.
10/3	2	Lockheed	Open Water	C	1.27	0.5	8	Air temperature = water temperature = 32°F.
10/6	3	Marco	Open Water	C	0.73	0.5	4	Air temperature = water temperature = 32°F.
10/6	5	Lockheed	Open Water	C	0.73	0.5	8	Air temperature = water temperature = 32°F.
10/7	7	Marco	Modification	C	0.73	0.5	4	Static ice processor.
10/7	8	Lockheed	Modification	C	0.73	0.5	8	All 24 vanes.
10/8	9	Marco	Modification	C	0.73	0.5	4	Freewheeling ice processor.
10/8	10	Lockheed	Modification	C	0.73	0.5	8	Reduced to 16 vanes.
10/9	11	Marco	Modification	C	0.73	0.5	4	Active ice processor.
10/9	12	Lockheed	Modification	C	0.73	0.5	8	Reduced to 8 vanes.

TABLE 2. CHRONOLOGICAL SUMMARY OF TEST PROGRAM (CONT'D)

Date (1975)	Test Number	Device	Type of Test	Oil Type	Thickness of Oil cm	Nom. Forward Speed fps	Nom. Belt or Drum Speed fps or rpm	Other Nominal Test Conditions
10/10	13	Lockheed	Performance	C	0.73	1.0	8	All 24 vanes for remainder of crude tests.
10/10	14	Lockheed	Performance	C	0.73	1.5	8	-
10/13	16	Marco	Modification	C	0.73	0.5	4	Unmodified.
10/15	18	Marco	Modification	C	0.73	0.5	4	Extended active ice processor.
10/15	19	Lockheed	Performance	C	0.73	0.5	13	-
10/16	20	Marco	Modification	C	0.73	0.5	4	Widened extended active ice processor.
10/16	21	Marco	Modification	C	0.73	0.5	4	As above without induction pump operating.
10/16	22	Marco	Performance	C	0.73	0.5	1	Widened extended active ice processor with pump.
10/16	23	Marco	Performance	C	0.73	1.5	4	Widened extended active ice processor with pump.
10/20	24	Marco	Modification	C	1.27	0.5	4	Widened extended active ice processor with pump.
10/20	25	Lockheed	Modification	C	1.27	0.5	8	-
10/21	26	Oil Mop	Other Units	C	1.27	0	0.15	Stationary test for 14 minutes.

TABLE 2. CHRONOLOGICAL SUMMARY OF TEST PROGRAM (CONT'D)

Date (1975)	Test Number	Device	Type of Test	Oil Type	Thickness of Oil cm	Nom. Forward Speed fps	Nom. Belt or Drum Speed fps or rpm	Other Nominal Test Conditions
10/21	27	Oil Mop	Other Units	C	1.27	0	0.15	Idler shifted 1 foot every 2 minutes.
10/21	28	Oil Mop	Other Units	C	0.73	0	0.15	Stationary test for 1 hour.
10/23	29	OSI	Other Units	C	0.73	1.35	-	Tethered to carriage.
10/23	30	JBF	Other Units	C	0.73	0.5	-	Tethered to carriage.
10/23	31	JBF	Other Units	C	0.73	-	-	Self-propelled.
10/30	38	Lockheed	Performance	C	0.73	0.5	3	-
11/6	-	-	Spreading	#2	Variable	-	-	In broken ice cover and in open water.
11/7	45	Marco	Open Water	#2	1.27	0.5	4	Air temperature = water temperature = 32°F.
11/7	46	Lockheed	Open Water	#2	1.27	0.5	8	Air temperature = water temperature = 32°F.
11/10	47	Lockheed	Open Water	#2	0.73	0.5	8	Air temperature = water temperature = 32°F.
11/10	48	Marco	Open Water	#2	0.73	0.5	4	Air temperature = water temperature = 32°F.
11/11	49	Marco	Performance	#2	0.73	0.5	4	Widened extended active processor.

TABLE 2. CHRONOLOGICAL SUMMARY OF TEST PROGRAM (CONT'D)

Date (1975)	Test Number	Device	Type of Test	Oil Type	Thickness of Oil cm	Nom. Forward Speed fps	Nom. Belt or Drum Speed fps or rpm	Other Nominal Test Conditions
11/11	50	Lockheed	Performance	#2	0.73	0.5	8	-
11/12	51	Marco	Performance	#2	0.73	1.0	4	Widened extended active ice processor.
11/12	52	Marco	Performance	#2	0.73	1.5	4	Widened extended active ice processor.
11/12	53	Lockheed	Performance	#2	0.73	1.0	8	-
11/12	54	Lockheed	Performance	#2	0.73	1.5	8	-
11/13	55	Marco	Performance	#2	0.73	0.5	1	Widened extended active ice processor.
11/13	56	Marco	Performance	#2	0.73	0.5	1.5	Widened extended active ice processor.
11/13	56A	Marco	Performance	#2	0.73	0.5	2.5	Widened extended active ice processor.
11/13	57	Lockheed	Performance	#2	0.73	0.5	3	-
11/13	58	Lockheed	Performance	#2	0.73	0.5	13	-
11/14	59	Marco	Modification	#2	1.27	0.5	4	Widened extended active ice processor.
11/14	60	Lockheed	Modification	#2	1.27	0.5	8	-
11/14	61	Oil Mop	Other Units	#2	1.27	0	0.15	Stationary test for 1 hour.
11/17	62	Marco	Modification	#2	0.73	0.5	4	Active ice processor (close-coupled).

TABLE 2. CHRONOLOGICAL SUMMARY OF TEST PROGRAM (CONT'D)

Date (1975)	Test Number	Device	Type of Test	Oil Type	Thickness of Oil cm	Nom. Forward Speed fps	Nom. Belt or Drum Speed fps or rpm	Other Nominal Test Conditions
11/17	63	Lockheed	Modification	#2	0.73	0.5	8	Reduced to 16 vanes.
11/18	64	Marco	Modification	#2	0.73	0.5	4	Freewheeling ice processor.
11/18	65	Lockheed	Modification	#2	0.73	0.5	8	Reduced to 8 vanes.
11/19	66	Marco	Modification	#2	0.73	0.5	4	Static ice processor.
11/19	67	Marco	Modification	#2	0.73	0.5	4	Unmodified.
11/20	68	Lockheed	Barrier	#2	1.27	0	3	Initially empty barrier.
11/20	69	Lockheed	Barrier	#2	2.54	0	3	Initially empty barrier.
11/20	69A	Lockheed	Barrier	#2	5.08	0	8	Initially empty barrier.
11/21	70	Lockheed	Barrier	#2	1.27	0.5	3	Barrier removed.
11/21	71	Lockheed	Barrier	#2	1.27	0.5	6	Barrier removed.
11/21	72	Lockheed	Barrier	#2	1.27	1.5	6	Barrier removed.
11/21	73	Lockheed	Barrier	#2	1.27	0.5	3	Static charge of oil in barrier.
11/21	74	Lockheed	Barrier	#2	1.27	0.5	6	Static charge of oil in barrier.
11/21	75	Lockheed	Barrier	#2	1.27	1.5	6	Static charge of oil in barrier.

TABLE 2. CHRONOLOGICAL SUMMARY OF TEST PROGRAM (CONT'D)

Date (1975)	Test Number	Device	Type of Test	Oil Type	Thickness of Oil cm	Nom. Forward Speed fps	Nom. Belt or Drum Speed fps or rpm	Other Nominal Test Conditions
11/21	76	Lockheed	Barrier	#2	1.27	0.5	3	Oil overcharge in barrier.
11/21	77	Lockheed	Barrier	#2	1.27	0.5	6	Oil overcharge in barrier.
11/21	78	Lockheed	Barrier	#2	1.27	1.5	6	Oil overcharge in barrier.
11/21	79	Lockheed	Barrier	#2	1.27	0.5	3	Barrier removed.
11/21	80	Lockheed	Barrier	#2	1.27	0.5	3	Static charge of oil in barrier.

crude having physical properties very closely matching the average properties of the four crudes thus far tested from the Prudhoe Bay fields was located in south Texas through the efforts of Mr. Robert E. Williams of Exxon Production Research Company. Arrangements were again made with the Exxon Production Research Company to supply crude oil from this same south Texas well for the Phase II test program.

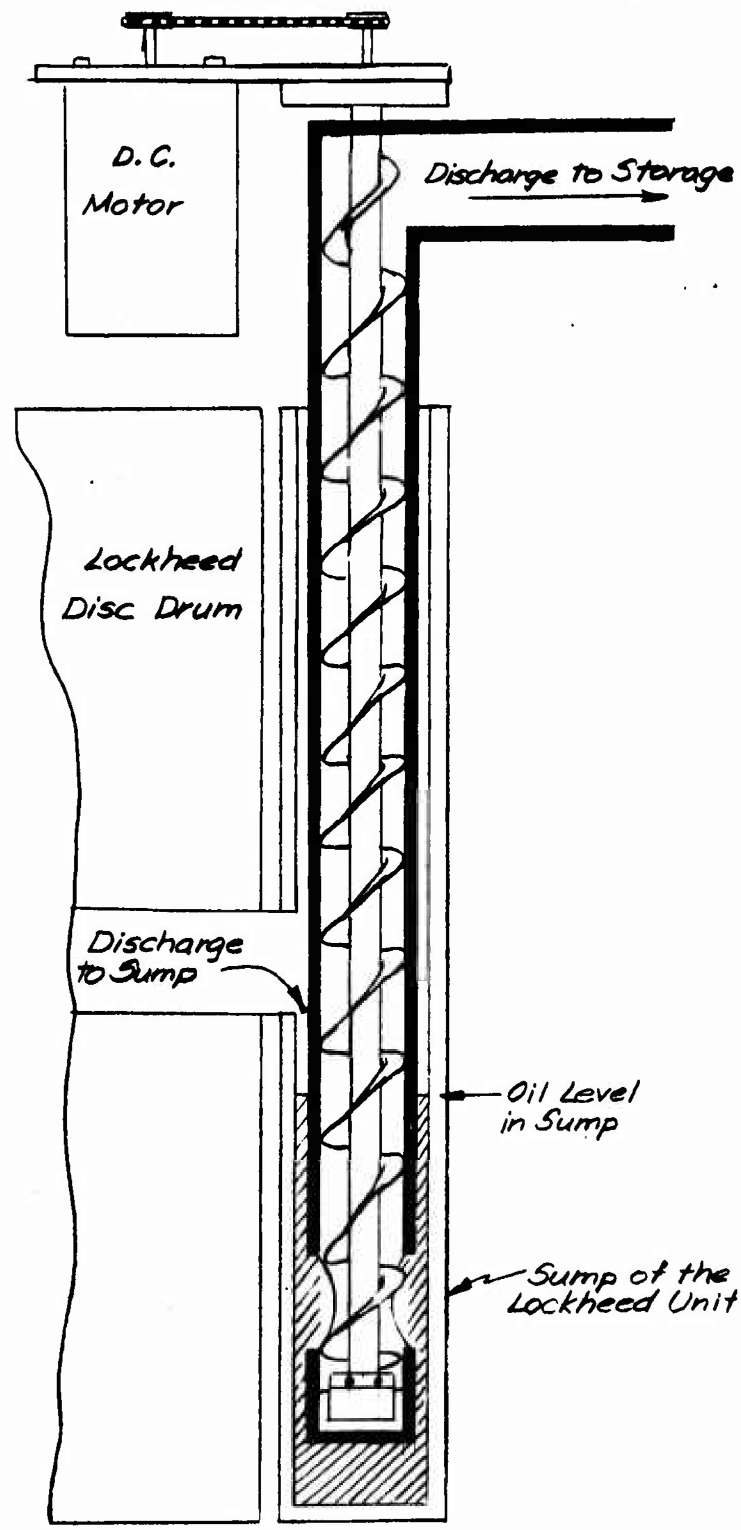
Included in the following sections of this report are descriptions of the laboratory equipment employed in the test program, the equipment modifications made to the Lockheed unit, and the equipment modifications made to the Marco unit. The test procedures used throughout the test program are described after which the test results are presented in summary form, and subsequently analyzed in detail. Finally, the conclusions drawn from the test program, and the recommendations based upon the test results, are presented. Included in appendixes are detailed descriptions of the oil spill recovery equipment tested in this program and descriptions of the measurement instruments and techniques used in the program.

EQUIPMENT MODIFICATIONS

Laboratory Equipment

During the course of the Phase I test program, problems associated with the operation of the Lockheed and Marco oil spill recovery devices were identified along with problems associated with the laboratory equipment used in the test program. The major problem associated with the laboratory and test equipment during the Phase I program was the inability to reliably pump the oil/ice/water slurry from the sumps of the oil recovery devices. This was a particular problem in the case of the Lockheed oil recovery device because of its extremely limited sump capacity and its relatively high oil recovery rate. This combination of sump capacity and oil recovery rate made the pumping problem critical since the inability of the pump to keep up with the deposition of oil in the sump required the termination of testing at the point at which the level in the sump reached the level of the central screw of the Lockheed unit. When this level was reached, a backup of oil within the unit would occur. The combination of sump capacity and oil recovery rate for the Marco unit was generally such that the sump did not have to be continuously emptied during a test. However, problems still arose in transferring the oil/ice/water mixture to storage containers upon the completion of a test with the Marco unit. The pump used most successfully but still with less than desirable results during the Phase I program was an air actuated double diaphragm pump. This pump would at times become either clogged with ice chips or the valves would be prevented from properly seating due to the capture of ice chips between the ball valves and the valve seats, thereby yielding the pump inoperative. For the Phase II program, a brief investigation into the pumping problem indicated that the most promising off-the-shelf equipment was a positive displacement progressing cavity pump. However, the cost of such a pump in the capacity required with a variable speed drive exceeded $3,000, an amount felt to be excessive for the purposes of this test program. Adapting commercially available pumps to the very narrow four inch wide sump of the Lockheed unit presented additional problems. As an alternative to this approach it was decided to design and build a vertical screw pump with a side intake and discharge, custom fitted to the Lockheed sump. Two earth augers having a three inch pitch were trimmed to fit with minimum clearance within a three inch ID length of plastic pipe. Based upon driving the unit with a 1750 rpm variable speed DC electric motor of 3/4 horsepower, and an efficiency of 66%, this screw pump was sized to provide an output of 60 gpm. Figure 1 is a sketch of this screw pump as installed within the sump of the Lockheed oil recovery device. This pump was intended to provide the capability of moving relatively large ice

FIGURE 1. SKETCH OF THE VERTICAL SCREW PUMP



pieces without damage to the pump or interference with the pumping rate. In addition, this pump would be capable of pumping extremely viscous fluids, such as cold crude oil. This pump performed extremely well throughout the entire test program.

The procedure used in the Phase I test program to raise and lower the Lockheed unit in and out of the water consisted of the use of blocks and hydraulic jacks. This procedure proved to be extremely time consuming and was designated as one of the items requiring change in the Phase II program. To facilitate the rapid raising and lowering of the Lockheed unit, a vertically adjustable support rig was fabricated allowing the height of the Lockheed unit to be adjusted by hand-operated winches. This lifting rig is shown in the photograph of Figure 2. When positioned in either its raised or lowered position, the device was braced directly to the carriage which provided a solid foundation. A safety grid was fabricated of expanded metal to protect operating personnel from the rotating drum and its sharp edged vanes. This safety grid is also shown in the photograph of Figure 2. The safety grid was fabricated in such a manner so as to allow its rapid removal for modification of the Lockheed unit, and the repair, removal, or replacement of its vanes. The cover nested into the carriage frame when in the lowered operating position. In its raised position, it rested on top of the Lockheed unit.

Clean-up of any laboratory facility after the completion of tests involving oil is always a major problem. The taped polyethylene liner installed in the model basin prior to the Phase I test program greatly assisted in minimizing the clean-up problem, however, it was not fully effective. In an attempt to improve upon this for the Phase II program, an oil resistant coating was first applied to the rubber liner of the model basin. After the oil resistant coating had cured, a polyethylene liner was fabricated with seams welded with a heat gun to form a positive barrier between the oil and the model basin. Following this, plywood buffer boards were placed over the plastic liner for about 1 foot on either side of the waterline to protect the plastic liner from the abrasive action of the ice. These procedures were more successful than the Phase I procedure, however, total protection of the model basin was still not achieved. In spite of these efforts, a small amount of oil still got behind the plastic liner, penetrated the oil resistant coating, and caused some blistering of the rubber liner of the model basin. In addition to the protective effort directed toward the model basin itself, all floors and walls of the test area were covered with a plastic sheet to protect them from coming in contact with splashed or spilled oil. In addition, the floor was covered with masonite sheeting to provide protection to the plastic sheet, and to provide an anti-skid footing for personnel.

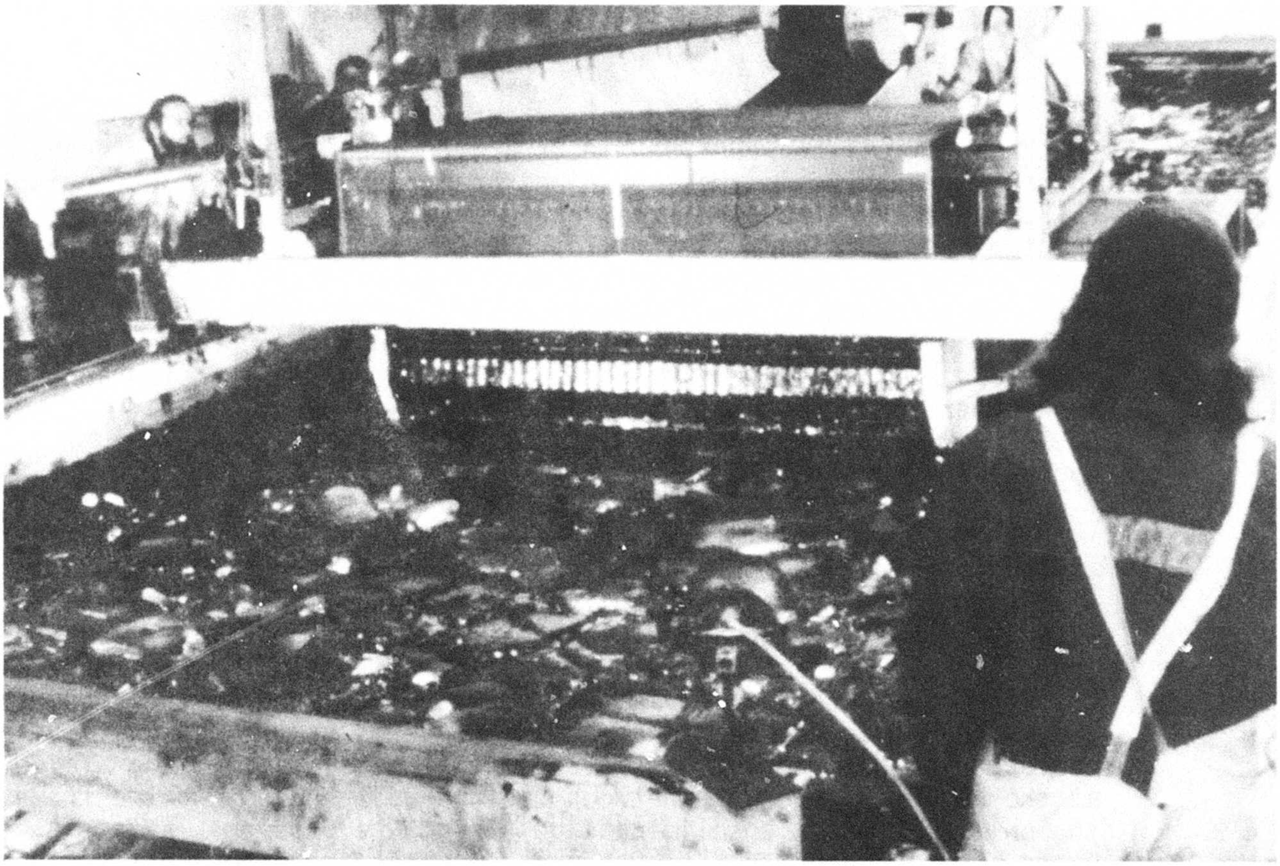


FIGURE 2. PHOTOGRAPH OF THE LOCKHEED UNIT SHOWING THE LIFTING RIG AND THE SAFETY GRID.

As was the case in the Phase I program, the Marco hydraulic power supply was adapted for use with both the Marco oil recovery device and the Lockheed oil recovery device. Since the small centrifugal pump supplied with the Marco unit was not employed in this program, the hydraulic lines were arranged such that the Marco selector switch operated the Marco unit when in the run position and the Lockheed unit when in the pump position. The hydraulic system was also fitted with a flow control valve, a reversing valve, and gages to assist in the setting of the drum speed of the Lockheed unit and the belt speed of the Marco unit. The capacity of the hydraulic system was adequate to operate the Lockheed drum at speeds up to 12 rpm in air.

A probe was designed to more accurately determine the actual thickness of oil between ice pieces in the model basin. The probe operated on the basis that the electrical conductivity of water is far greater than the electrical conductivity of oil. The probe, mounted on a vernier scale, would be visually set at the upper surface of the oil and then inserted into the oil until the electrical meter indicated that the oil/water interface had been pierced. The difference in the vernier readings would then provide the actual thickness of the oil at that position. Figure 3 is a photograph showing the oil thickness probe in use.

Lockheed Device

In the Phase I test program one of the major problems identified in operating the Lockheed unit in broken ice cover consisted of damage to the vanes, primarily at their ends, due to interaction with the ice. The vanes would bend at times to the extent where they would come in contact with and jam against the top frame of the unit, stopping drum rotation. This problem was eliminated in the Phase I program by strapping the vanes at the two ends of the drum with wire cables. Another problem consisted of the occasional jamming of ice at the bottom of the unit between the end of the drum and the frame of the unit. In order to eliminate both of these problems, a fairing or guard was designed to extend below the waterline from the frame of the unit to approximately 1 inch beyond the end of the vanes, thereby protecting the vane ends and simultaneously eliminating the possibility of ice jamming between the drum and the frame. Figure 4 is a photograph of the guard installed on one end of the drum. Also shown in Figure 4 is the strapping that was used to further ensure that the vanes would not be bent up at their ends. This strapping was only installed for the first few tests of the Phase II program; after tests revealed that the fairing effectively eliminated the problem, the additional use of strapping was dropped.

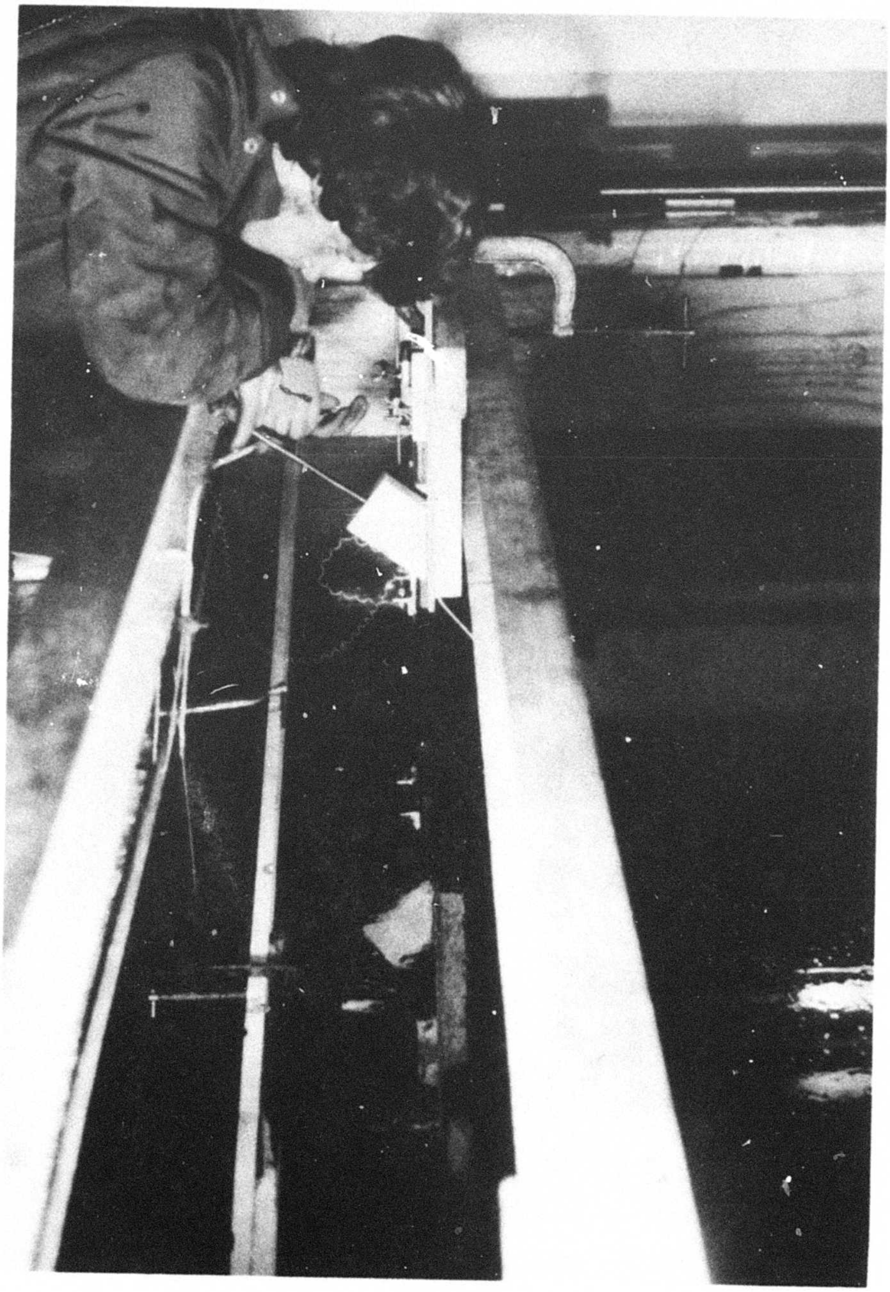


FIGURE 3. PHOTOGRAPH OF THE OIL THICKNESS PROBE IN USE.

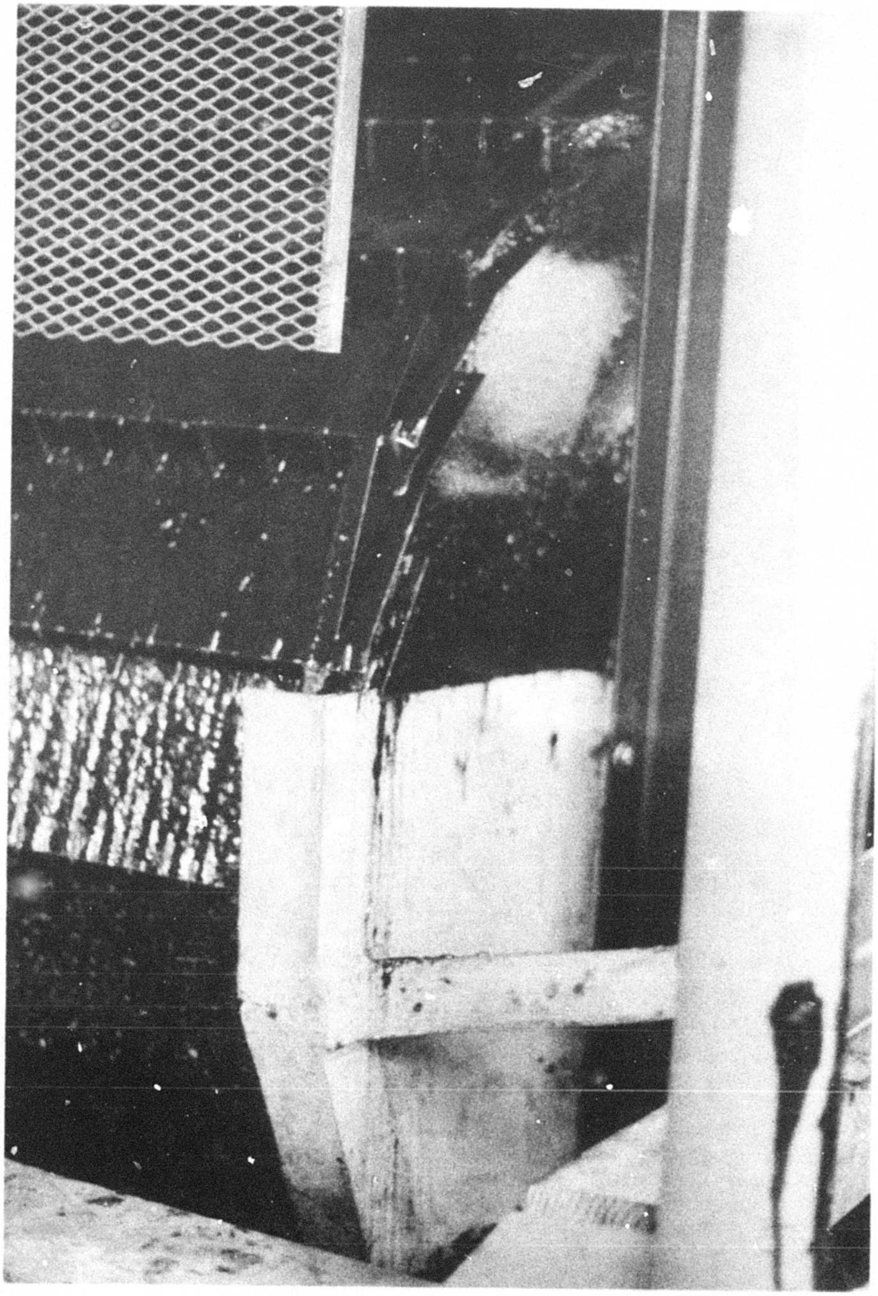


FIGURE 4. PHOTOGRAPH SHOWING THE GUARD AND VANE STRAPPING INSTALLED ON THE LOCKHEED UNIT.

As the Phase II program progressed, an attempt was made to increase the throughput efficiency of the Lockheed unit by adding a barrier to the downstream side of the unit. Tests incorporating the barrier were conducted at the conclusion of the planned test program. These tests were very brief in nature and were conducted in ice-free open water, but at low temperatures. The barrier consisted of two sideboards extending from the two sides of the Lockheed unit with a connecting end barrier, and two wipers designed to seal the region between the sideboards and the rotating drum at the waterline. Figure 5 is a sketch of this arrangement.

Marco Device

As far as the operational aspects of operating the Marco oil spill recovery device in ice infested waters are concerned, the Phase I test program identified the major problem to be the ice pile-up at the nose of the boom of the Marco unit. This pile-up of ice tended to act as a barricade, pushing oil away from the unit, and causing some damage to the belt of the unit through tearing and abrasion. In addition, for the case of the more viscous oils, any significant build-up of ice on the nose of the unit tends to reduce the oil recovery of the unit through the conveyor effect. In very viscous oils, the Marco device recovers oil not only by the absorption of oil within the pores of the Filterbelt, but additionally through the layering of a heavy coating of oil on the surface of the belt, which then acts essentially as a conveyor. If ice pieces are riding on the nose of the unit, they tend to wipe off this surface coating of heavy oil thereby reducing the oil recovery rate of the unit. A major portion of the effort in the Phase II program was therefore directed towards the development of concepts for ice processing equipment which could be added to the Marco oil recovery device with the objective of eliminating, or at least minimizing,the problems associated with the interaction of the Marco belt with broken ice cover. The effort was directed towards the development and preliminary evaluation of concepts, rather than the development of hardware intended for future use in field applications.

Sixteen ice processing concepts applicable for use with the Marco oil spill recovery device were presented for consideration. Sketches of these sixteen concepts are shown in Figure 6. Concept A is a simple static cage surrounding the nose of the Marco unit, consisting of cables, rods, or straps mounted on a steel frame. In operation, this grid work would tend to deflect the ice slightly down and around the nose of the Marco unit while allowing the oil to pass through to the collection device.

Concept B is a freewheeling open drum device, again constructed of cables, rods, or straps mounted on three support discs.

FIGURE 5. SKETCH OF THE BARRIER ADDED TO THE DOWNSTREAM SIDE OF THE LOCKHEED UNIT FOR A BRIEF SERIES OF OPEN WATER TESTS

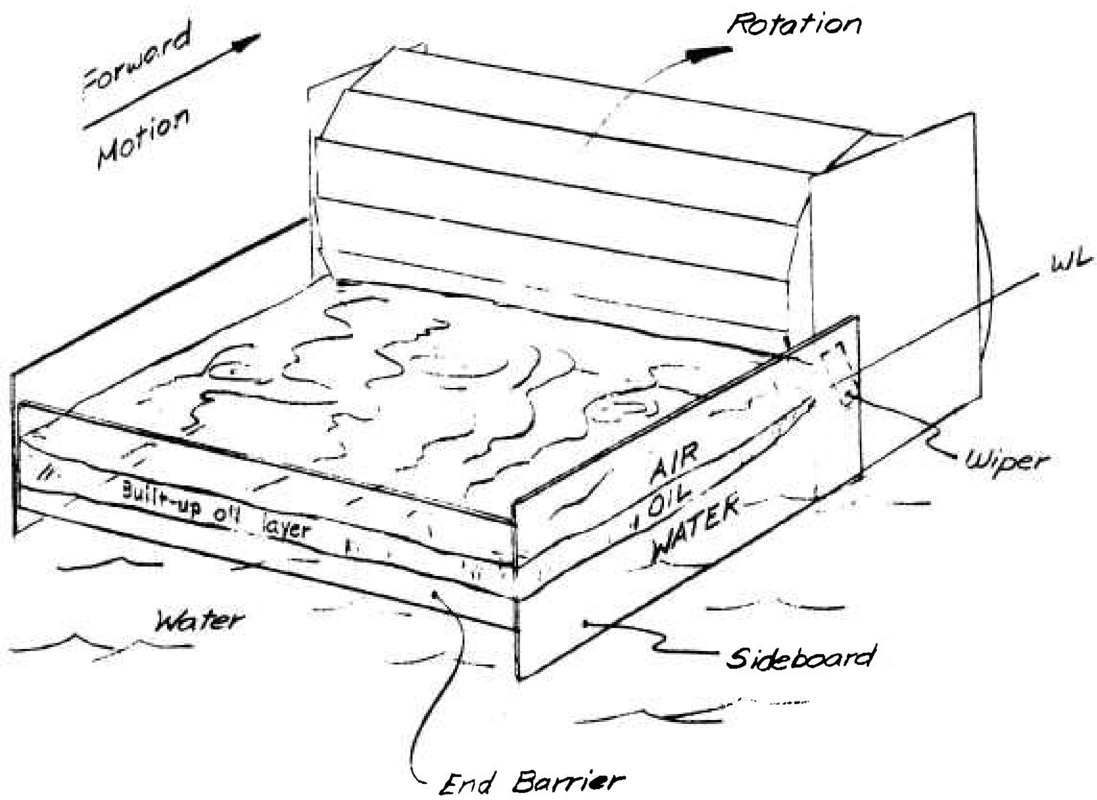
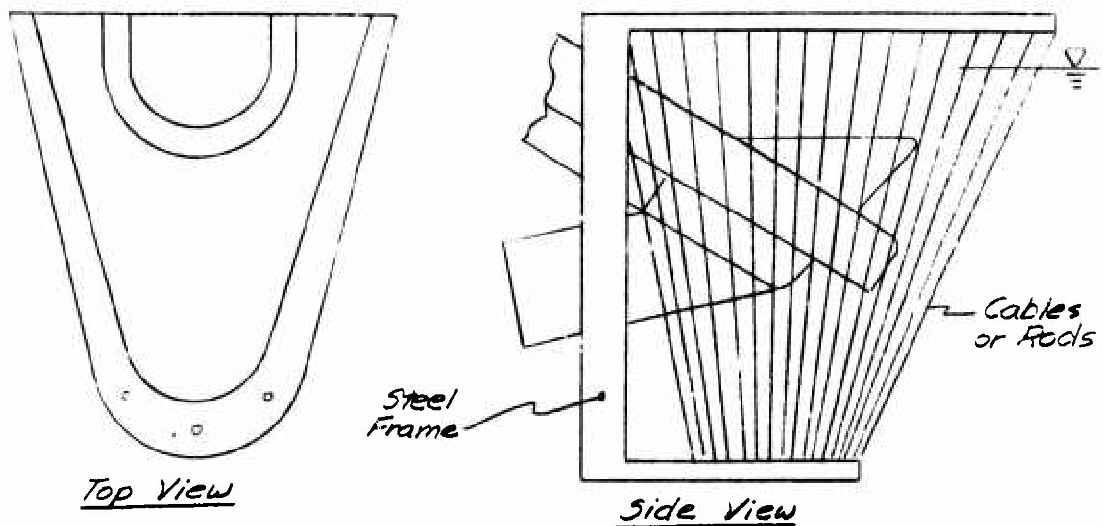
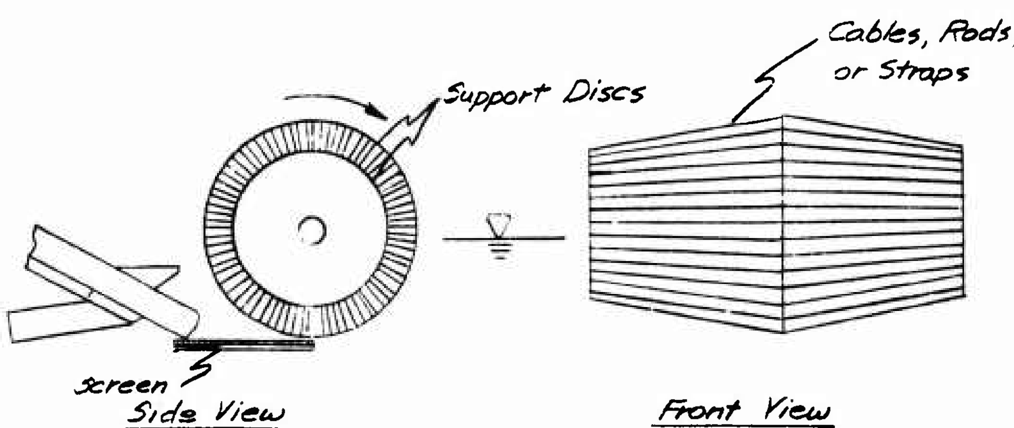


FIGURE 6. ICE PROCESSING CONCEPTS DEVELOPED FOR USE WITH THE MARCO OIL SPILL RECOVERY DEVICE

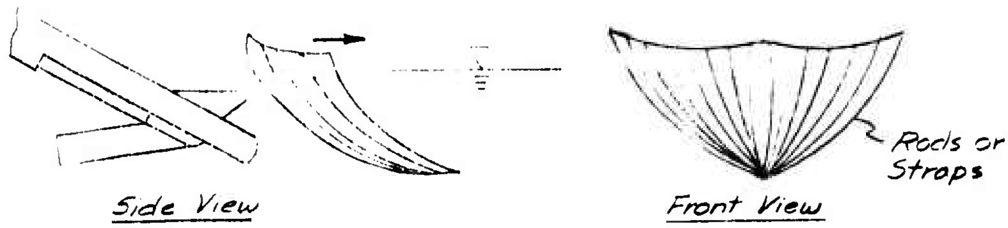


Concept A. Static Cage.

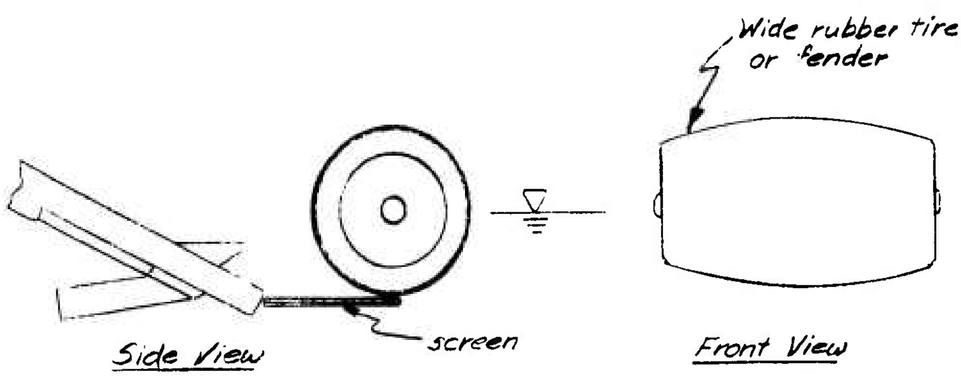


Concept B. Freewheeling Open Drum.

FIGURE 6 (continued)

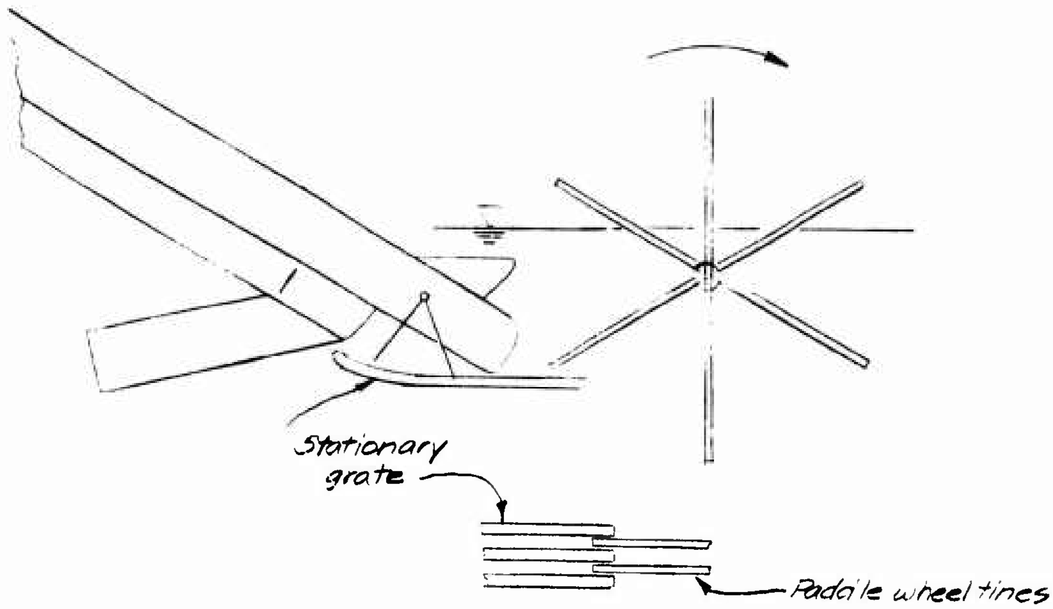


Concept C. Static Cowcatcher.

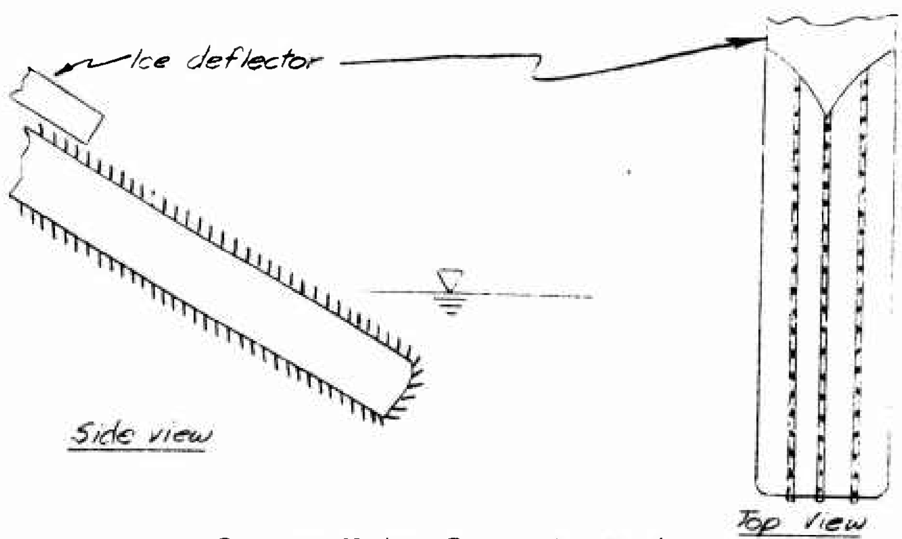


Concept D. Freewheeling Closed Drum

FIGURE 6 (continued)

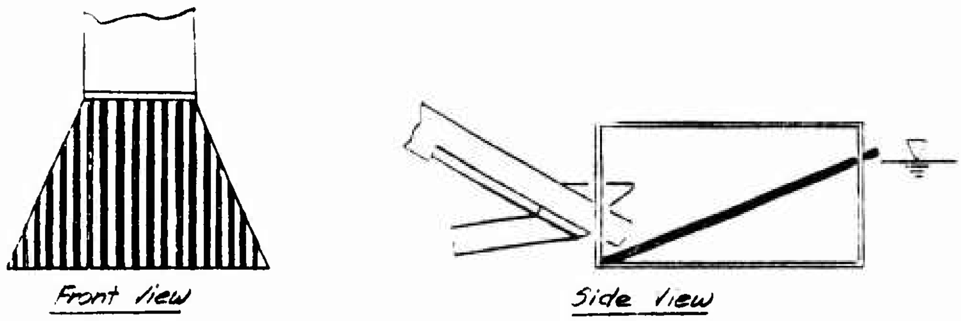


Concept E. Driven Spoked Paddle Wheel

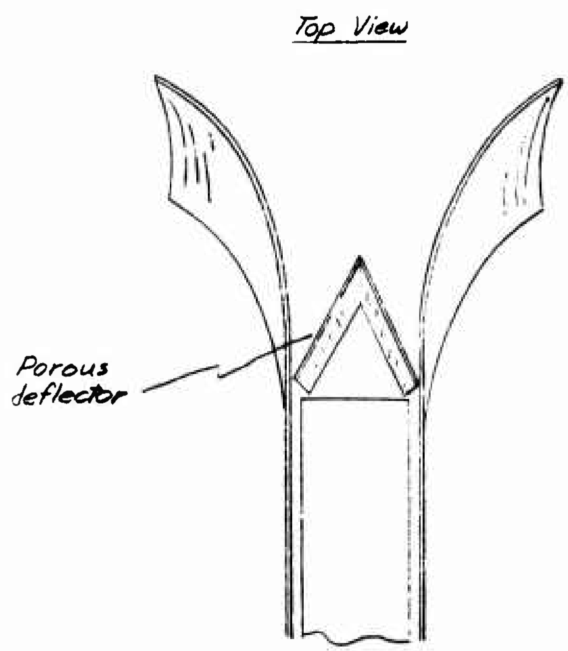


Concept F. Ice Processing Spikes Added to Filterbelt

FIGURE 6 (continued)

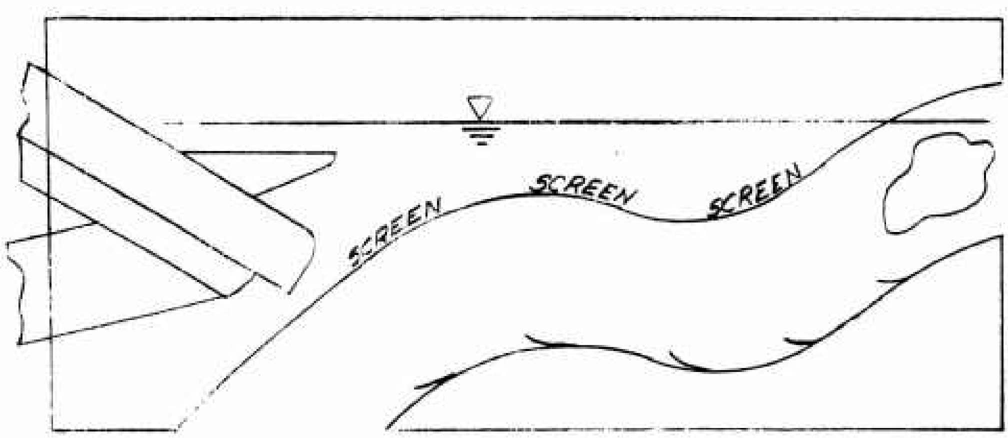


Concept G. Static Grating Ramp.



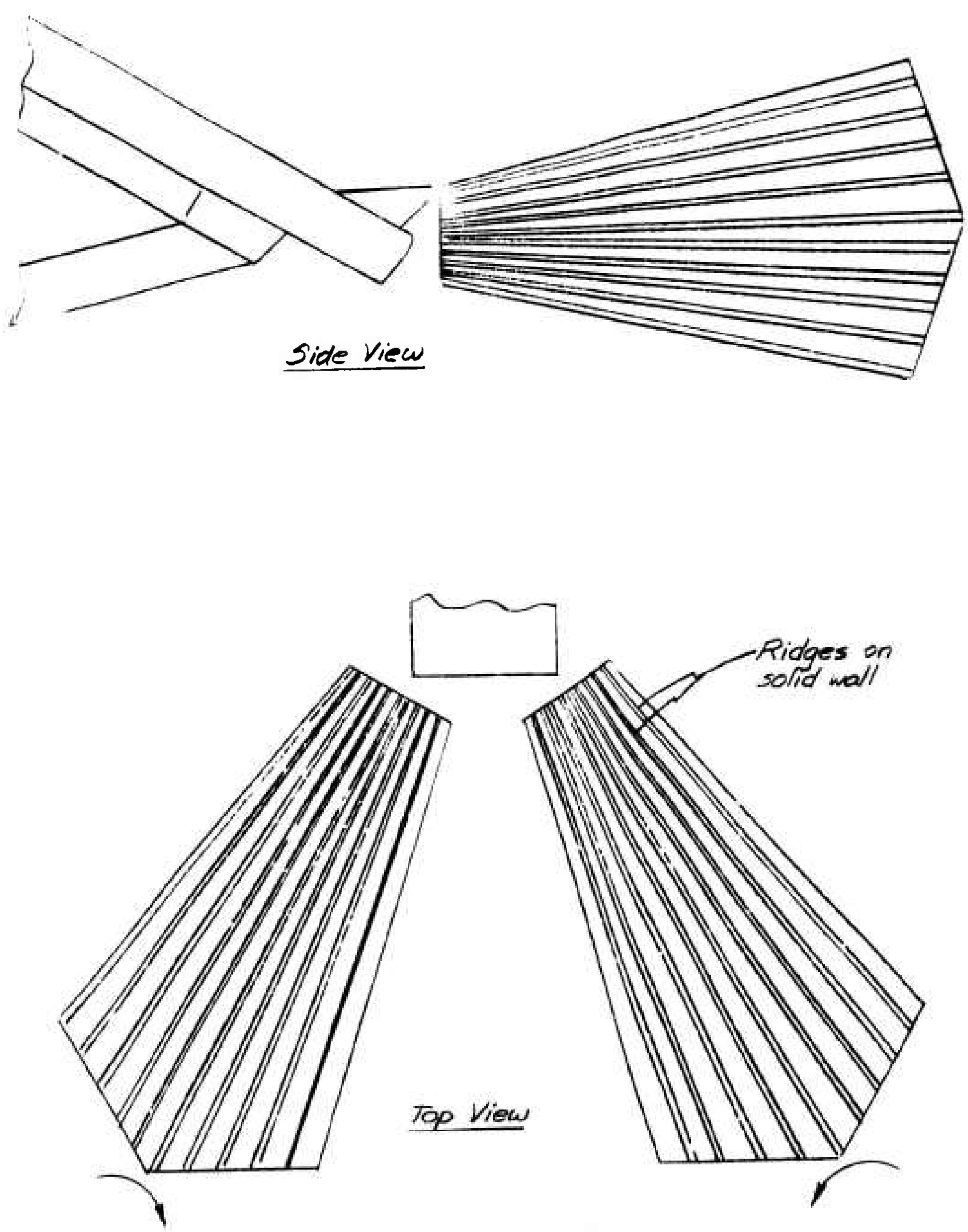
Concept H. Static Deflector.

FIGURE 6 (continued)



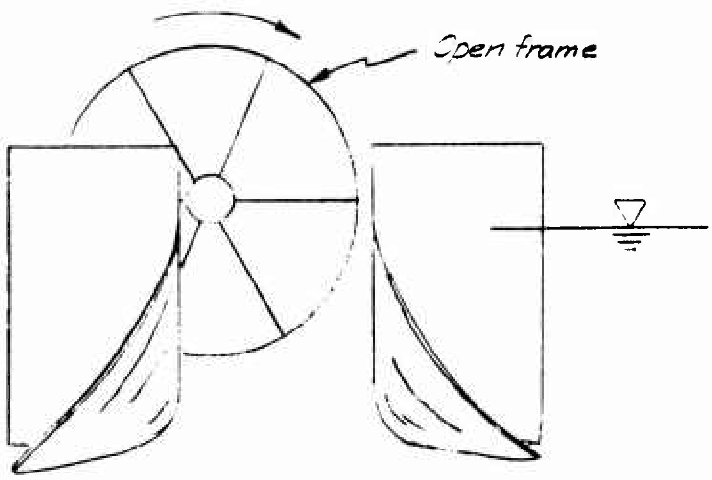
Concept I. Screened Channel

FIGURE 6 (continued)

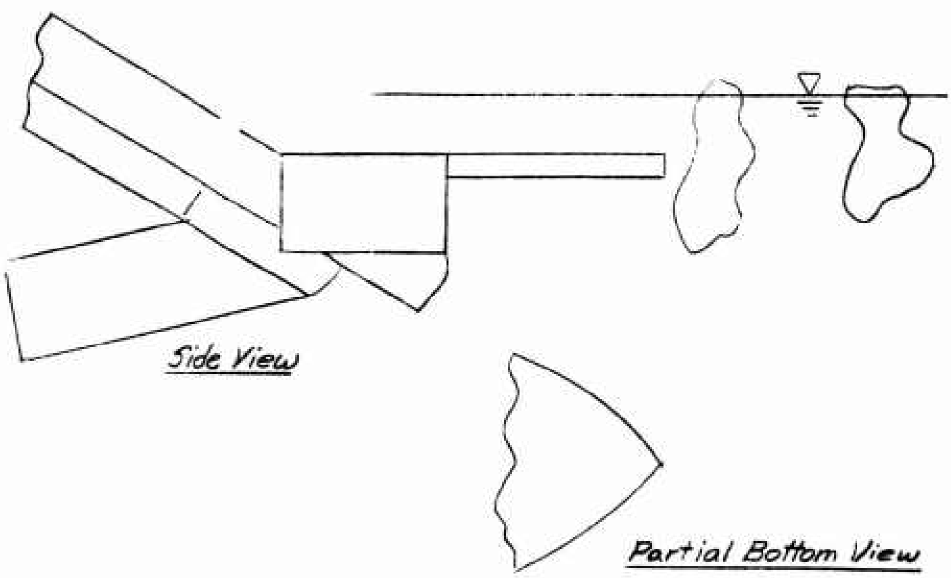


Concept J. Driven Axial Tumblers.

FIGURE 6 (continued)

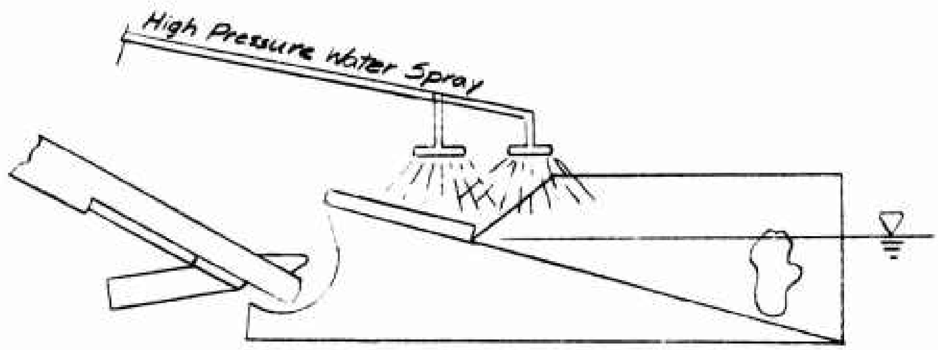


Concept K. Sweep Wheel

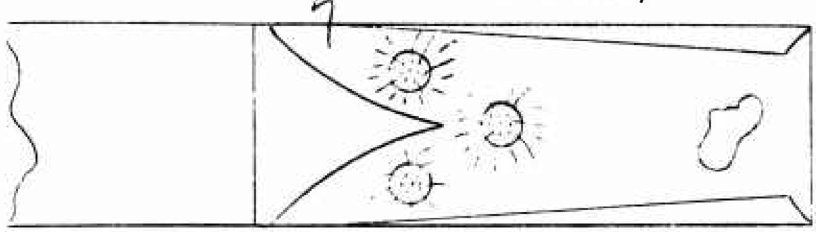


Concept L. Underwater Deflector.

FIGURE 6 (continued)



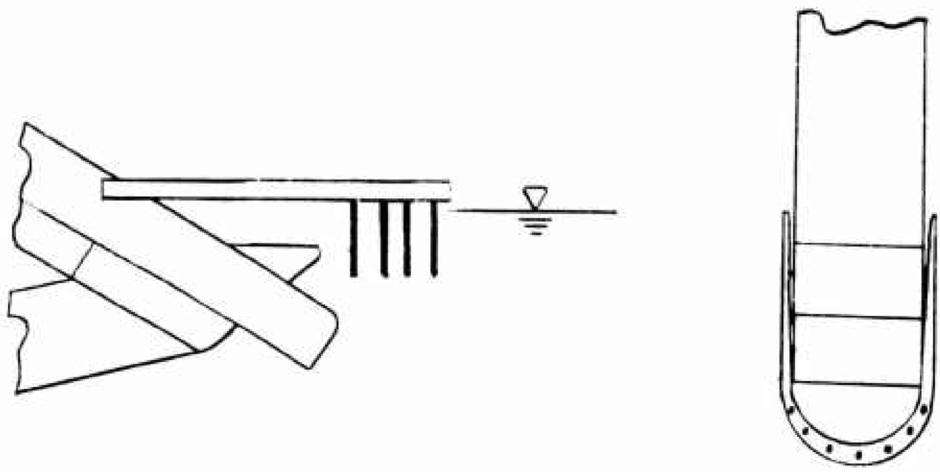
Side View



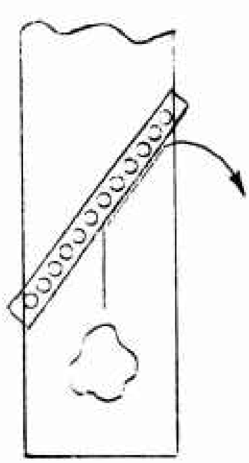
Top View

Concept M. Deflector Ramp with Water Spray Wash

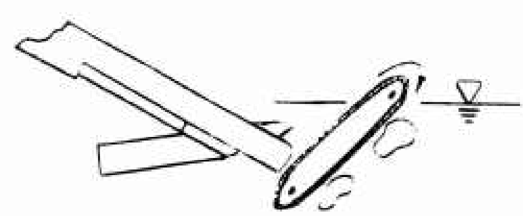
FIGURE 6 (continued)



Concept N. Vertical Deflector Rods



Concept O.
Belt Deflector Rods



Concept P. Driven Mesh.

This unit would be installed such that the centerline of the free-wheeling drum would be several inches above the water surface, with the result that the forward motion of the device would impart a rotational motion to the freewheeling open drum. This motion would then cause a suppression of the ice below the nose of the Marco unit while allowing passage of the oil to the collection device.

Concept C is a static cow-catcher type of device consisting of straps or rods connected to a support frame. The lower portion of the device is well below the waterline and curved such that as the device encounters ice, the ice would be lifted somewhat and moved to the side, while the oil would be allowed to pass through.

Concept D is another freewheeling device, similar in principal to the freewheeling open drum previously described, but of simplified construction, such as a wide rubber tire or a solid fender. The region between the processor and the Marco boom would have to be protected from the reentry of ice by using suitable screening for all of these devices.

Concept E is a driven spoked paddle wheel. The paddle wheel consists of a series of spokes which would rotate between a complimentary stationary series of spokes mounted beneath the boom of the Marco unit. This processor would have to be driven with a suitable motive device. In operation, as the spoked paddle wheel rotates and ice encounters it, ice would be caught between the spokes of the wheel, driven down and under until it was caught by the stationary grate, at which time the entrapped ice would be cleared from the spoked paddle wheel and progress aft beneath the boom of the Marco unit.

Concept F consists of a modification to the existing Filterbelt of the Marco unit, rather than an appendage attached to the Marco unit. In this concept, a series of spikes would be added to the Filterbelt to provide the foundation for recovering ice on the belt itself, the ice being supported some distance clear of the belt by the spikes. This clearance would allow for the layering effect of oil to occur on the Marco belt. As the spiked belt lifted the ice off the surface of the water and carried it along, the ice would eventually meet an ice deflector mounted part way up the boom, which would then deflect the ice off the Filterbelt and dump it back into the water.

Concept G is a simple static grating inclined from above the water level at the inlet end to below the Marco boom at the discharge end. The grating could be a simple series of rods. The sides of the grating could either be straight sided or angled, the angled version, of course, resulting in an increase in the sweep width of the unit.

As ice encountered this unit it would tend to build-up ahead of the grating until the force was sufficient to push the ice down beneath the grating and discharge it behind the boom of the Marco unit, while the oil would pass through the grating to be collected.

Concept H is a deflector of relatively complex form which would tend to provide the same general type of ice processing as described in the previous paragraph for the static grating. As ice encounters the unit, it would tend to be depressed downward to the point where the Marco unit could pass over the top of the ice while allowing the floating oil to pass into the collection area.

Concept I is a screened channel which could be either a static device or an active, or driven, device. In the static configuration, an S-shaped screen is provided to channel the ice in a tumbling fashion below the oil suction point of the Marco boom. The tumbling path is intended to improve the inherent removal of oil from the ice pieces. In an active configuration, the upper screen of the channel could be driven to assist the ice in traversing through the channel.

Concept J consists of a pair of axially ribbed tumblers which would rotate in a fashion so as to depress the ice downward and to the side as the oil recovery device encountered it, while allowing the straight through passage of the oil. Modifications of this concept could consist of cylindrical tumblers rather than conically shaped tumblers, and installing the conically shaped tumblers in a reversed orientation such that the small end is forward. This configuration would result in a greater intake sweep and a lower tumbler tip speed at the oil recovery end.

Concept K consists of a sweep wheel which rotates in a plane perpendicular to the plane of motion of the Marco oil recovery device. The intent of this device is to periodically sweep the area immediately ahead of the Marco intake, thereby clearing the area of ice pieces by moving them down and to the side of the unit while allowing the relatively clear passage of oil to the collection device.

Concept L is a simple static underwater deflector which would effectively deflect the large ice pieces encountering the Marco unit, while allowing for some accumulation of smaller ice pieces at the suction point of the belt. With this device there is no interaction between the processor and the oil being collected.

Concept M is a multi-curved surface ramp, intended to deflect the gathered ice pieces, combined with a high pressure water spray wash which would wash the oil coating from the surface of the ice pieces collected. After being cleaned of oil with the high pressure

water spray, the ice pieces would then be deflected off to the side of the unit, while the undisturbed oil would proceed through to the collection area.

Concept N is another simple static device consisting of a series of vertical deflector rods which would deflect the ice pieces around to the side of the unit while allowing relatively free passage of the oil.

Concept O is an approach directed towards removing ice pieces from the surface of the Filterbelt, rather than preventing the ice pieces from ever encountering the Filterbelt. This concept consists of a simple series of deflector rods which would tend to channel any collected ice pieces off to the side of the belt as they advanced up the boom of the unit with the Filterbelt.

Concept P is a driven mesh mounted a few inches above the surface of the ice at the forward end of the boom and a few inches below the bottom of the Marco boom at the trailing end. The mesh could consist of an open conveyor belt material having a relatively open screen, and the device would be rotated at a speed corresponding to the forward speed of the unit, such that ice would be gathered and deflected down and under the boom of the Marco unit as the unit advanced in a forward direction through the oil/ice/water mixture. As the ice is driven down and under the unit, the oil would be allowed to pass through the open mesh of the processor to the collection area of the Marco boom.

The planned Phase II program provided for the testing of three ice processing concepts applied to the Marco oil spill recovery device. Consequently, of the sixteen concepts proposed, three were chosen for further development and for testing in the laboratory. One processor was selected from each of the general categories of static processor, active non-driven processor or freewheeling processor, and active driven processor. On the basis of its simplicity of construction, its ruggedness, and its totally below water orientation, the static processor selected for further consideration was the processor identified as Concept L, the underwater deflector. The device built, shown in Figure 7, was designed as a further extension of the platform on the forward end of the Marco boom, with angled sides intended to gradually deflect the larger ice pieces to the side as the unit advanced through the ice field. The upper surface of the static ice processor was located about 2 inches below the surface of the oil/water interface. While it was realized that small ice pieces would be relatively unaffected by this ice processor and would simply flow over the top of the unit, the static ice processor would effectively deflect large ice pieces away from the suction area of the Marco oil

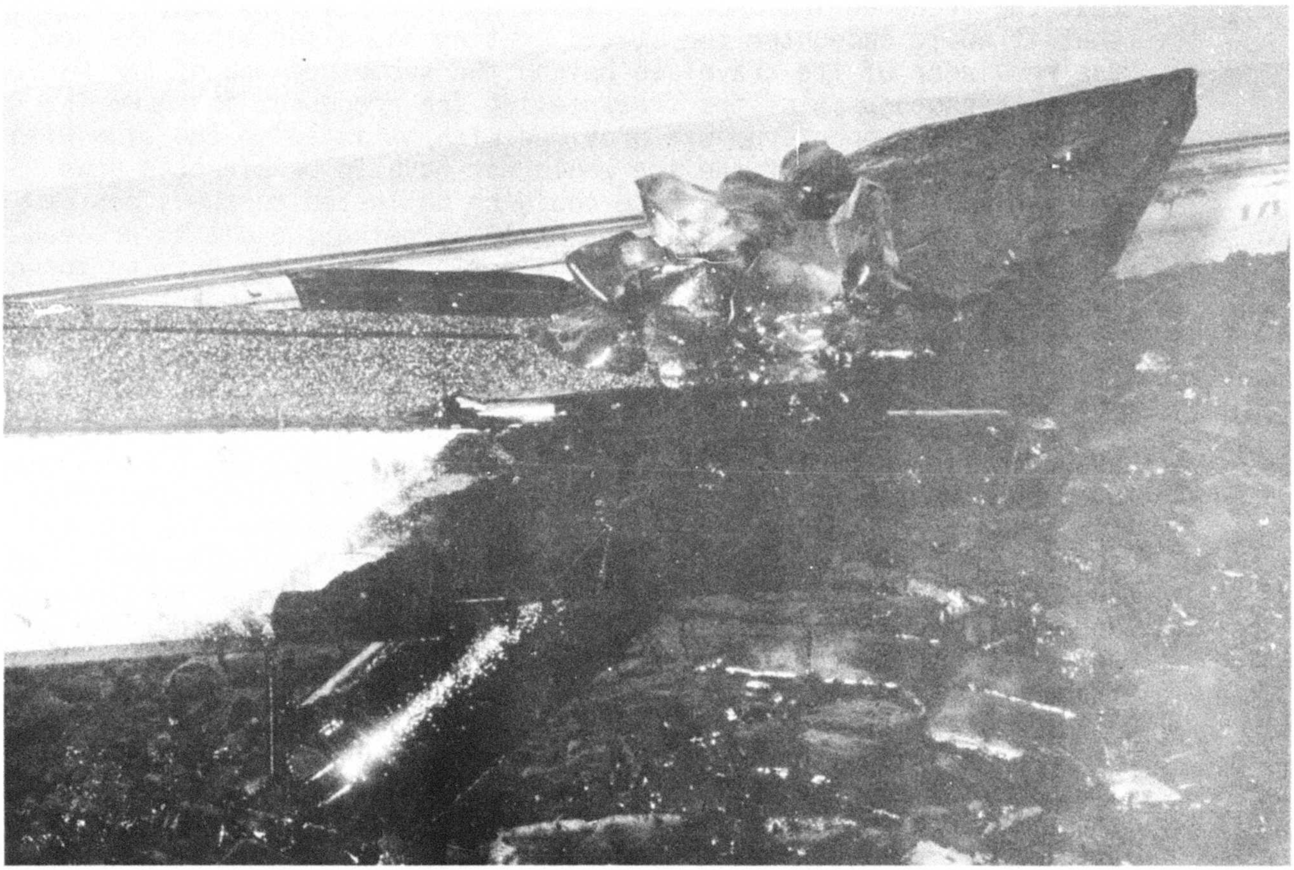


FIGURE 7. PHOTOGRAPH OF THE STATIC ICE PROCESSOR MOUNTED ON THE BOOM OF THE MARCO DEVICE (BOOM RAISED CLEAR OF THE WATER).

spill recovery device. The unit built for testing in the laboratory consisted simply of a 2 inch angle iron frame with a solid plywood platform. The solid plywood insert insured that ice pieces could not tumble over or under the frame and become lodged within the frame.

The active non-driven processor, designated as the freewheeling ice processor, selected for further development and testing in this program was a combination of Concept B, the freewheeling open drum, and Concept G, the static grating ramp. In operation, it was intended that the freewheeling open drum would deflect ice down to the extent that it would encounter the static grating and slide along the grating the remainder of its travel to beyond the submerged end of the Marco boom. A photograph of the freewheeling ice processor is shown in Figure 8. The open drum was provided with an angle to the side with the intent that all of the ice would not have to be directed down and behind the unit, rather ice could be deflected to the sides of the Marco boom with equal success while allowing the oil to proceed through the ice processor to the collection unit. The driving force for the device would be provided by the incoming ice impacting the wheel below its centerline, thus providing a rotation which would help to depress the ice below the surface and clear it aft of, or on the side of, the advancing oil spill recovery device. The freewheeling processor was mounted directly to the boom of the Marco unit as shown in Figure 8. The three discs supporting the straps were of plywood construction. The straps themselves were made from steel flat bar. The freewheeling processor rotated in standard pillow blocks supported on a two inch steel angle frame. To prevent the deflected and depressed ice from resurfacing between the freewheeling processor and the nose of the Marco boom, the area between the devices was screened with a section of expanded metal mounted on a steel angle frame.

In initial concept, the active ice processor was similar to that identified previously as Concept P. In this form, the active ice processor, as shown in Figure 9, was mounted in a close-coupled position directly on the boom of the Marco unit. The processor itself consisted of a driven open mesh steel belt fabricated from one inch mesh conveyor belt material, mounted such that the forward end was about 2 inches above the ice surface and the lower end extending just below the lowermost portion of the Marco boom. Side boards were added to the unit between the active processor and the boom to prevent the reentrance of deflected ice within that region. The active ice processor was driven by a variable speed DC motor. As the test program proceeded, further modifications were made to the active ice processor. The first test conducted with the close-coupled active processor raised the possibility of oil being processed down and under the unit along with the ice. In order to provide

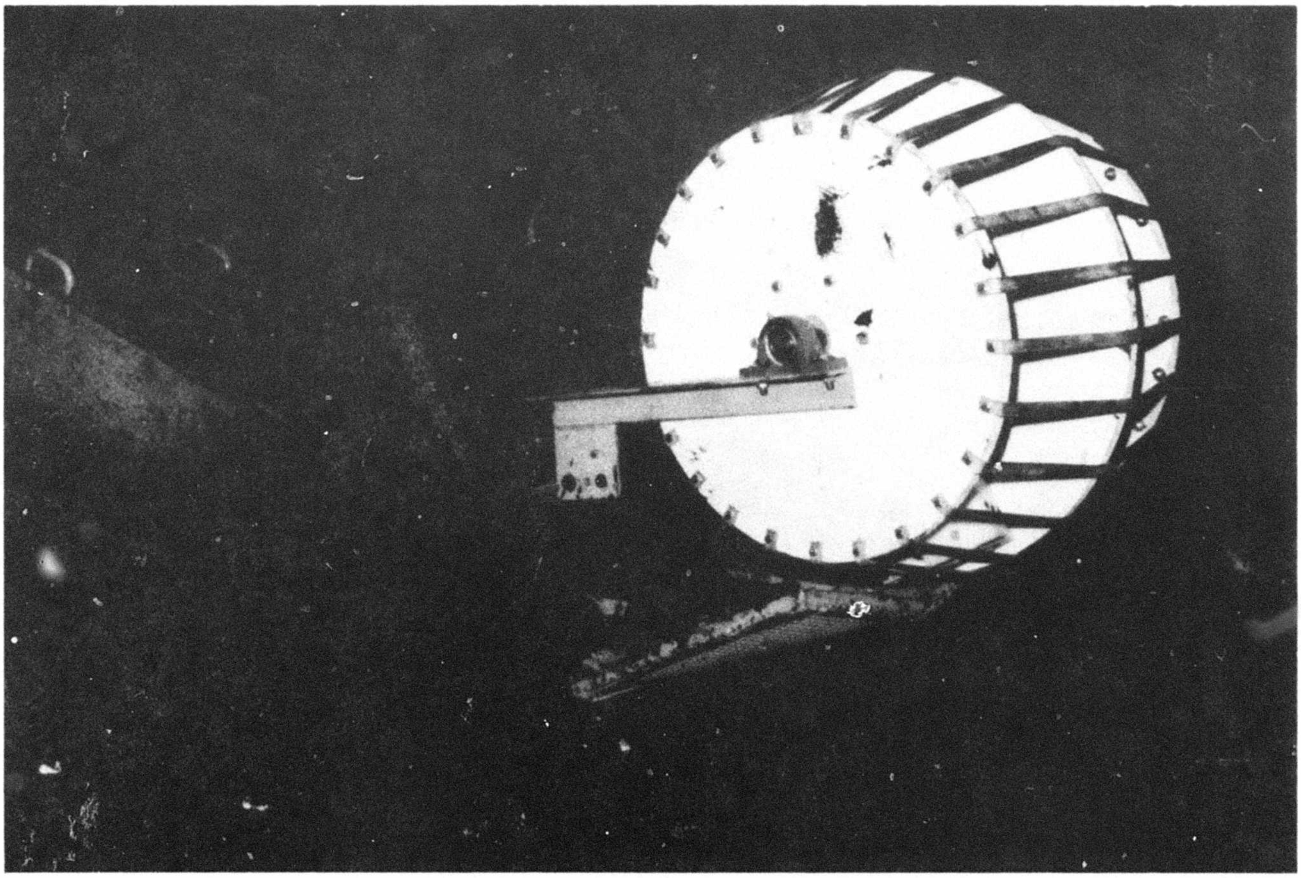


FIGURE 8. PHOTOGRAPH OF THE FREEWHEELING ICE PROCESSOR MOUNTED ON THE BOOM OF THE MARCO DEVICE (BOOM RAISED CLEAR OF THE WATER).

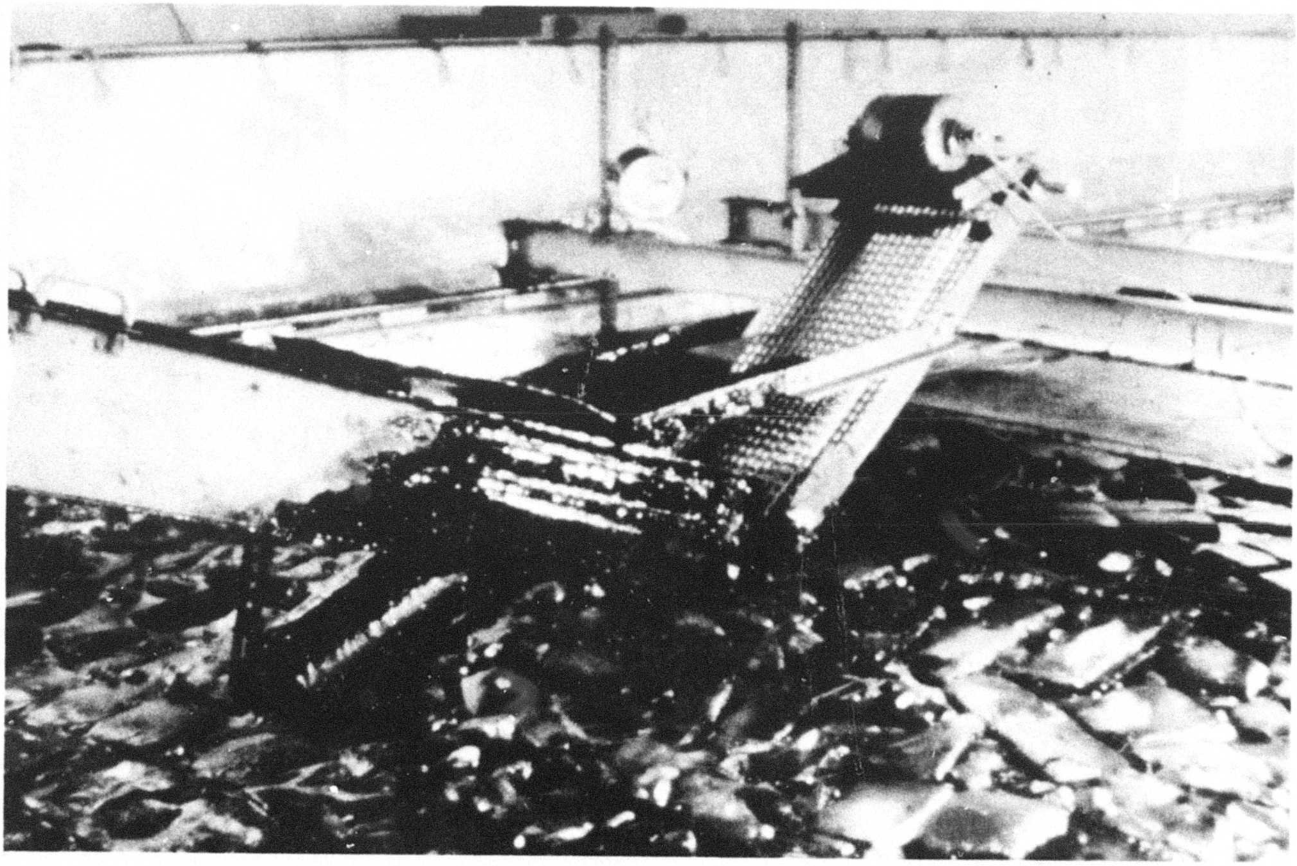


FIGURE 9. PHOTOGRAPH OF THE CLOSE-COUPLED ACTIVE ICE PROCESSOR MOUNTED ON THE BOOM OF THE MARCO DEVICE (BOOM RAISED CLEAR OF THE WATER).

time and space for the oil to resurface before passage of the Marco oil spill recovery device, the active ice processor was extended forward approximately 8 feet and mounted from a separate carriage. The region between the active ice processor and the boom of the Marco unit was then screened off with a barrier fabricated from 2 inch chain link fencing to prevent the reentrance of ice pieces. This modification was then further refined after it was observed that the very viscous crude oil tended to be trapped within the open area between the chain link mesh sides of the ice barrier. In order to facilitate the breaking away of the very viscous crude oil from the chain link fencing, the ice barrier was widened from the active processor end to the Marco belt end. This configuration is shown in Figure 10. The bottom portion of the screen varied from a flat horizontal surface at the active processor end of the screen to an angled section at the Marco boom end to assist in the clearing of ice from the screen as the assembly moved through the ice field. The two inch mesh of the chain link fencing allowed some small pieces of ice to enter within the screened area, but the small ice pieces were not judged to be a major problem. A mesh size less than two inches was considered for screen construction and rejected in consideration of the very heavy crude oil to be used in the test program, and the expected difficulty of passing such heavy oil through a relatively fine mesh.

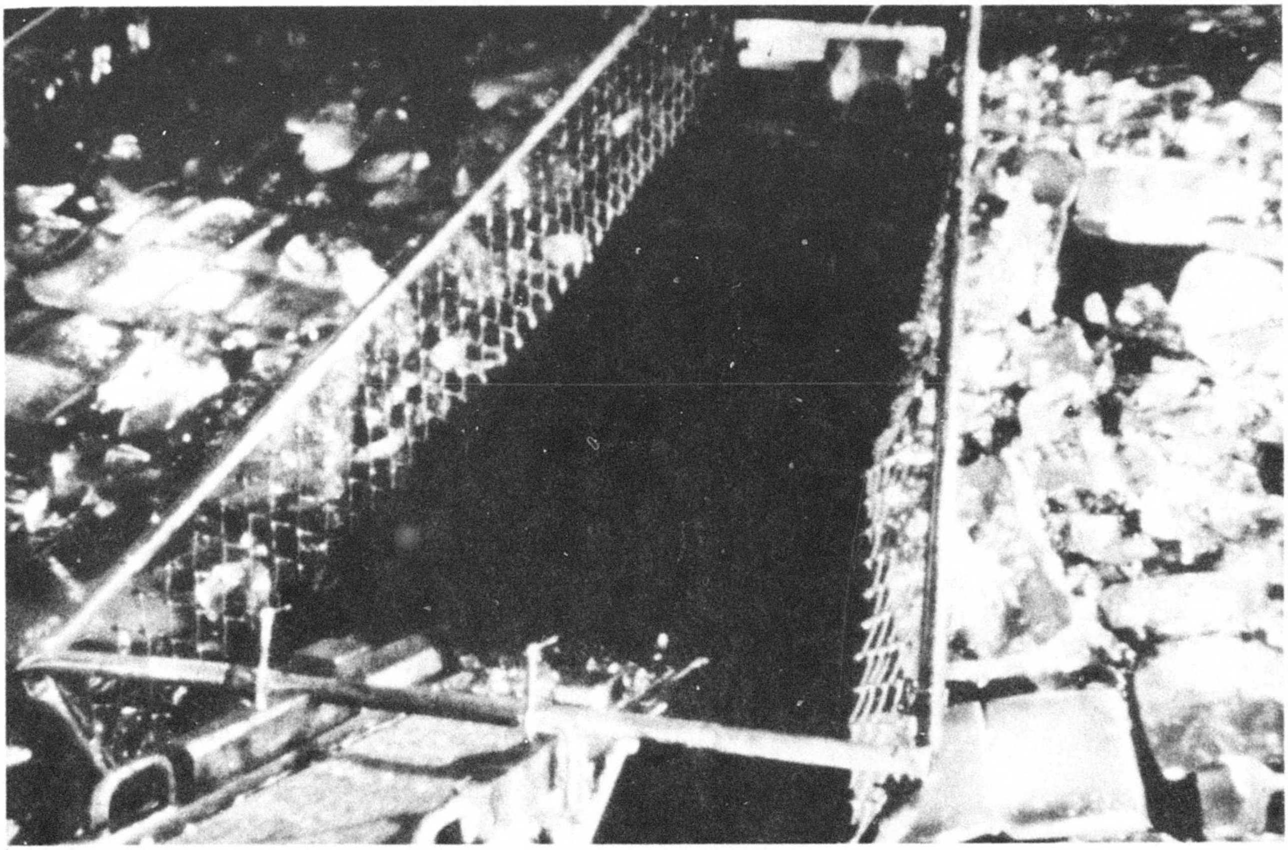


FIGURE 10. PHOTOGRAPH OF THE WIDENED SCREEN EXTENDED ACTIVE ICE PROCESSOR UNDERGOING TEST IN NO. 2 FUEL OIL.

TEST PROCEDURES

The test set-up employed in the Phase II testing of the Lockheed and Marco units was basically similar to the test set-up used in Phase I. The main towing carriage of the model basin was modified to provide the primary means of support for both the Lockheed and Marco units as shown in Figure 11. ARCTEC's Ice Model Basin measures 100 x 12 x 6 feet, length, width, and depth respectively. The model basin is situated within a heavily insulated chamber. Refrigeration is accomplished by a mechanical refrigeration system to +15°F, or by the controlled injection of liquid nitrogen into the basin to -150°F. The main towing carriage spans the width of the basin and travels on ball bushings along stainless steel cylindrical rails. The carriage is driven over a speed range of 0.01 to 20 fps by an endless pretensioned stainless steel cable, which is in turn driven by a variable speed electric motor located outside of the cold room. The speed of the drive system is regulated to within 0.5% by an electronic feedback loop controlling an eddy current clutch. In order to install the Lockheed and Marco devices on the main towing carriage, some modifications were required. The interior structure of the main carriage was removed to allow for the installation of the Lockheed unit within the main frame of the carriage. The lifting frame constructed for the Lockheed unit was positioned on the main carriage. Additional structural members were attached to the main carriage to provide the support for the Marco unit, and for the work platforms located on either side of the Marco unit.

The power unit supplied with the Marco oil spill recovery device was used to provide hydraulic power to both the Lockheed and the Marco devices. This power package consisted of a 6.3 hp air cooled Petter diesel engine driving a hydraulic pump and an air compressor. The power unit was located outside the ice model basin and the pneumatic and hydraulic lines were passed through the basin wall.

As was the case in Phase I testing, the test program was based upon running each device in one-half the length of the model basin. A wooden divider was fabricated to span the width of the basin thereby separating the prepared ice/oil field into two equal lengths of 50 feet. This partition permitted a test to be performed in one half of the basin with one device without disturbing the oil in the remaining half of the basin. The test of the other device under the same conditions would subsequently be conducted in the undisturbed half of the basin. Tests of the Lockheed and Marco devices were run from the mid-point of the basin towards each end of the basin. The transfer of the collected oil/water/ice mixture from the sump of the Marco device was performed with a Weldon model M-8

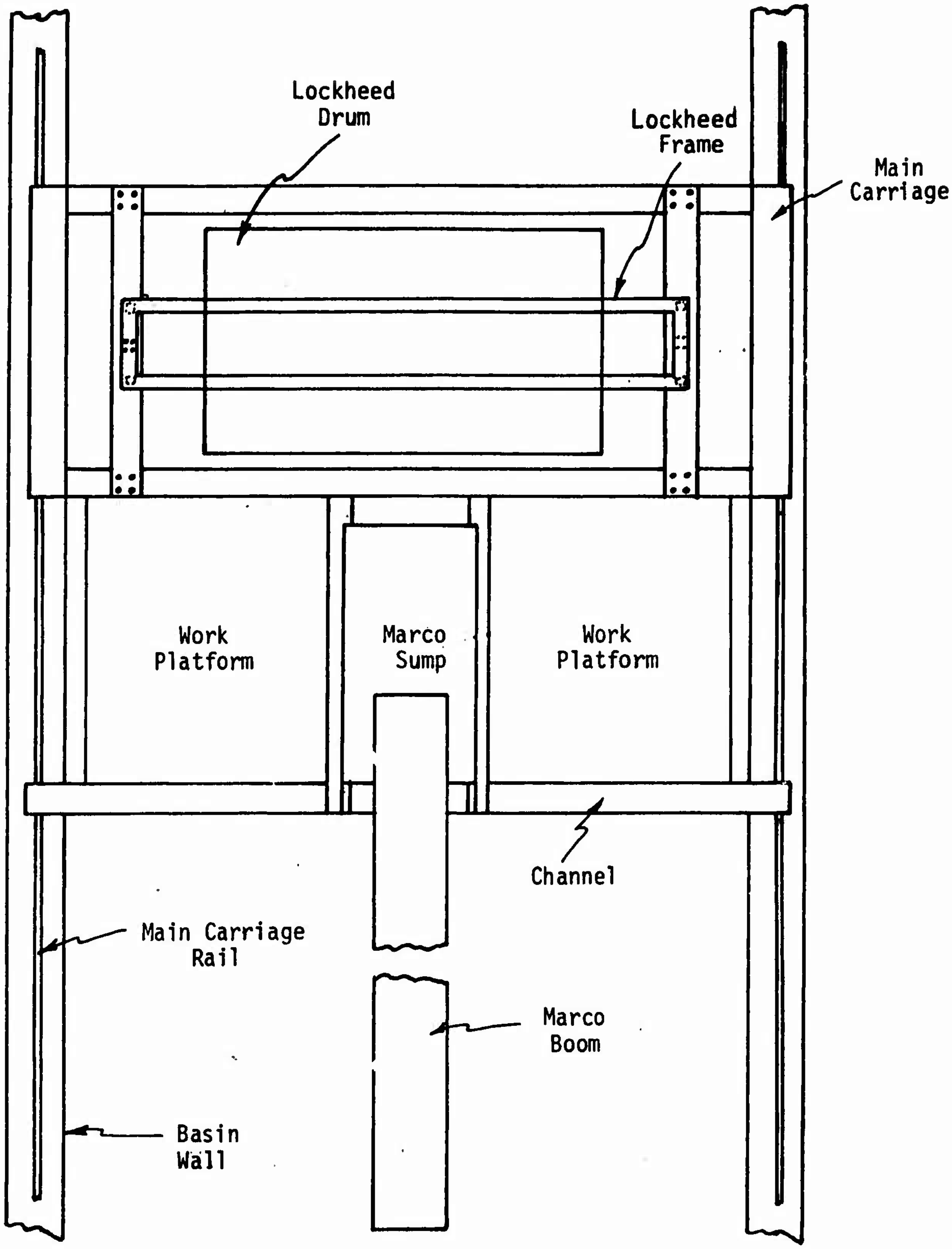


FIGURE 11. SKETCH OF THE INSTALLATION OF THE LOCKHEED AND MARCO OIL RECOVERY DEVICES IN THE MODEL BASIN.

air operated double diaphragm pump. The sump of the Marco unit had adequate holding capacity so that the sump did not have to be continuously pumped during a test, rather it could be pumped in its entirety at the conclusion of the test. In the case of the Lockheed unit, the ARCTEC-built rotary screw pump was used throughout the test program. The extremely limited capacity of the Lockheed sump required that it be pumped continuously during each test. The self-priming feature of both of these pumps was vital to their successful operation in the test program. The sump of the Lockheed unit was discharged directly into a 55 gallon open drum which was moved along the walkway adjacent to the model basin as the device progressed down the length of the model basin.

Since the test program called for relatively limited testing of the three additional oil spill recovery devices, the OSI Skimmer, the JBF DIP, and the Oil Mop, provision was made for a less permanent installation of these devices. The OSI Skimmer and the JBF DIP were installed at opposite ends of the model basin, and towed through a tether arrangement attached to the main carriage from the end of the basin towards the middle of the basin. In the case of the JBF unit, the control console was hand carried from the walkway on the side of the basin and the oil discharge hose led to the main carriage and then to the oil recovery drum. The flexible-bodied OSI Skimmer proved to be a more difficult device to place in the model basin. After being placed in the water the central flexible well area was flooded with basin water and all air bubbles were removed from beneath the flexible area. The discharge hose from the device was run to a following work carriage, and then discharged over the side of the basin to a collection drum.

The small Oil Mop unit tested was relatively portable and easy to handle. The squeeze roller portion of the Oil Mop device was mounted at a level slightly above the walls of the model basin. The rope of the Oil Mop was cut to the desired length and fused together after being passed through the squeeze rollers, the idler rollers and the idler pulley. The idler pulley was simply tied to a beam spanning the model basin. An Oil Mop rope length of 70 feet was used, giving an effective length from the squeeze rollers to the idler pulley of about 35 feet. The vertical lift of the unit at the squeeze roller end was approximately 1 to 1-1/2 feet.

The general testing procedure involved the preparation of the water/ice/oil condition on the afternoon preceeding the day of testing thereby allowing the test area to soak overnight at the desired

temperature and achieve equilibrium conditions. On the day of testing, the first task consisted of obtaining all of the pre-test data required. The pre-test data requirements and the data required during and following the test, identified as the post-test data, are summarized in Table 3. In taking the pre-test data, several samples were used for each measurement to insure that representative values were obtained. The oil properties measured and the measurement techniques used are described in Appendix B. Following the collection of the pre-test data the oil recovery devices were prepared for testing. For the Marco unit, pre-test preparation consisted of insuring that all system components were operational including the belt squeeze rollers, the belt tensioning device, and the belt drive. For testing, the boom was then lowered to the specified depth for the test, the Filterbelt was rotated, and as soon as oil entered the sump the forward drive system was activated. At the completion of the run, the forward drive system and the Filterbelt were stopped simultaneously.

In the case of the Lockheed unit, test preparations consisted of rotating the unit in air before lowering it into the oil/ice/water mixture to insure that it was ice-free and operating properly. The drum was then lowered to the specified depth and primed over a length of 15 to 20 feet to insure that vane and disc coating was uniform, and that the rotational speed of the drum as affected by the disc coating was as constant as possible. During this priming process, the sump of the unit was pumped out and the oil recirculated back to the basin behind the oil recovery device. At the start of the data run, the discharge piping was put in place to direct the pump discharge from the sump to the oil collection drum. At the termination of the test, both the drum rotation and the forward travel of the unit were stopped simultaneously. In the case of both the Lockheed and the Marco units, full documentation of each test was provided by still photographs and movies, and by notes made in a daily log book. Following each day's testing, preparations were made for the tests to be conducted on the following day.

The testing procedure for the OSI Skimmer included priming of the collection well and the pump with a measured amount of oil prior to the test. The pump was operated throughout the entire test to insure that no overflow of oil occurred within the collection well. At the conclusion of the test, the oil level within the collection well was again recorded to allow a determination as to whether any additional build-up of oil had occurred in the well region during the course of the test. Preparations for testing of the JBF DIP consisted of priming by running the belt in oil prior to engaging the forward drive system. The pump of the unit was also checked for satisfactory operation prior to the test. The belt of the unit was operated at its maximum speed during the entire test sequence.

TABLE 3. DATA REQUIREMENTS AND METHODS

A. Pre-Test Data

1. Oil specific gravity - remove sample from surface and test
2. Oil viscosity - remove sample from surface and test
3. Oil surface tension - remove sample from surface and test
4. Oil temperature - measure with thermometer in place
5. Oil emulsification - remove sample from surface and test
6. Oil thickness - measure thickness over water with gage
7. Ice thickness - measure with rule and large calipers
8. Ice cake size - record typical size and range measured with rule
9. Ice percent coverage - estimate
10. Ice temperature - remove sample, crush, insert thermometer
11. Water temperature - measure with thermometer in place six inches below bottom surface of ice slabs
12. Target drum or belt speed
13. Target speed of advance

B. Post-Test Data

1. Actual drum or belt speed - time counted rotations with stop watch
2. Actual speed of advance - time measured length with stop watch
3. Time of recovery - time test duration with stop watch
4. Total volume recovered - measure total volume of oil, water, and ice recovered.

TABLE 3. DATA REQUIREMENTS AND METHODS (CONT'D)

5. Oil/water/ice recovery rate - divide 4 by 3

6. Oil volume recovered - measure volume of oil recovered after settling and centrifuging of a sample

7. Oil recovery rate - divide 6 by 3

8. Recovery efficiency - divide 6 by 4 and multiply by 100

9. Volume of oil encountered - calculate from swath width times oil thickness

10. Throughput efficiency - volume of oil recovered versus theoretical volume of oil encountered, divide 6 by 9 and multiply by 100

11. Recovered oil viscosity - remove sample and test

12. Recovered oil specific gravity - remove sample and test

13. Recovered oil emulsification - remove sample and test

14. Recovered oil surface tension - remove sample and test

15. Absorption of oil by ice - remove a standard 6 x 6 inch sample, record ice thickness and visual penetration of oil into the ice, melt sample and measure resulting volumes of oil and water

16. Notes of test observations

For the tethered tests, the air operated propulsion system was not placed in operation. The oil detector system was activated prior to the test. The test procedures employed for the Oil Mop unit were somewhat unique and are fully described in the section of the report entitled "Analysis of Tests of Other Units in Ice."

TEST RESULTS

Spreading Tests

The Phase I test program was conducted with nominal oil thickness of one-half inch and two inches. Oil was actually deposited in the laboratory on a volumetric basis, with the volume deposited based upon the nominal thickness of the oil spread over the entire twelve hundred square foot surface area of the model basin without consideration of the ice cover. In the Phase I program, the actual measured thickness of oil between ice pieces corresponding to the one-half inch nominal oil thickness was about two inches, while that corresponding to the two-inch nominal thickness was about five inches. While these oil slick thicknesses were selected as being representative of the range of interest, the natural equilibrium thickness to which the oil would spread under the test conditions remained a question. A brief series of tests in the Phase II program was therefore directed towards answering this question. The results would then be used to guide the selection of oil slick thicknesses to be used in the Phase II program. The spreading tests were therefore directed towards determining the equilibrium oil slick thickness which would be obtained by crude oil and No. 2 fuel oil when spilled on the surface of open water and ice-infested water with all temperatures initially at 0°C (air, water, ice and oil temperature).

The first spreading tests conducted were those with crude oil in broken ice cover. A 12-foot square area of the model basin was prepared with broken ice cover similar to that which would be present for the oil recovery device portion of the test program. A pouring basin, consisting of a cylinder of expanded metal with a solid bottom, was then suspended in the oil/ice mixture. The purpose of the pouring basin was to ensure that as the oil was poured into the basin, it entered the water/ice field with only a horizontal velocity component. Oil was initially added in three-gallon increments. As the test progressed, several interesting phenomena were observed. As the first three-gallon increment of oil was added, it was apparent that the oil would not spread to any great extent, the oil being contained to some degree by the ice. A photograph of the spreading test after the first three-gallon increment of crude oil had been deposited is shown in Figure 12. As additional oil was spilled, the new oil had a tendency to spread out over the top of the old oil which appeared to set up a bit in the interim, with the new oil tending to submerge some of the old oil and some of the ice, which gradually pushed aside some other pieces of ice. Figure 13 is a photograph of the test after twelve gallons of oil had been deposited. The areal extent of the oil coverage is seen to be not that much greater than was the case after the first three-gallon increment had been deposited. Since the oil seemed to be primarily building up in

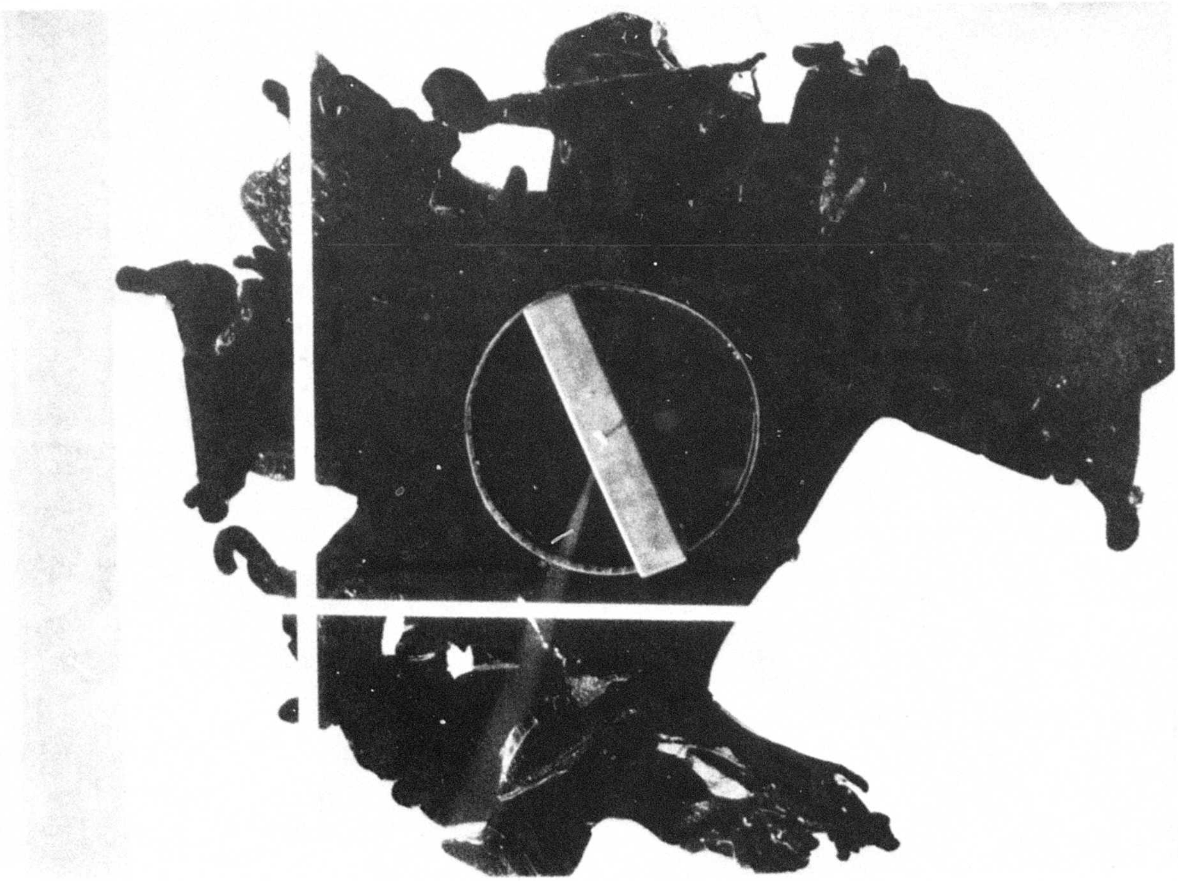


FIGURE 12. PHOTOGRAPH OF THE CRUDE OIL SPREADING TEST IN ICE INFESTED WATERS AFTER THREE GALLONS HAD BEEN DEPOSITED.

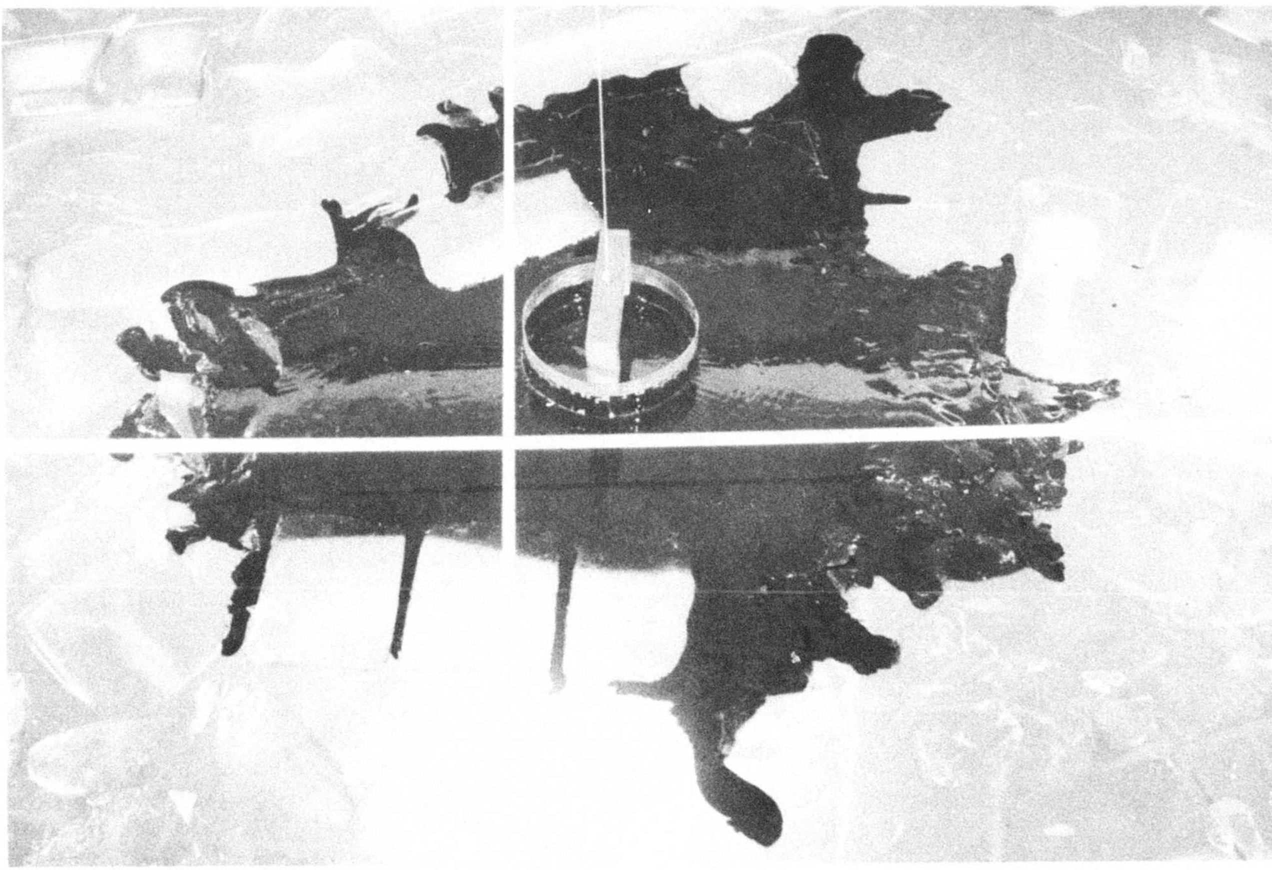


FIGURE 13. PHOTOGRAPH OF THE CRUDE OIL SPREADING TEST IN ICE AFTER TWELVE GALLONS HAD BEEN DEPOSITED.

thickness, rather than spreading, as oil was added, a twelve-gallon increment was added in a single pour after the initial twelve gallons had been poured in three-gallon increments. Figure 14 is a photograph of the test after 24 gallons had been deposited. In comparing this photograph with the two previous photos, it is seen that some of the ice has been submerged, while some additional ice has been moved further away from the original position. The surface area of the oil at this point was approximately 30 square feet, while the thickness of the oil measured about 3.75 inches at the center, varying to about 2.5 inches near the boundaries. Figure 15 is a photograph taken as the final twelve-gallon increment of oil was deposited, showing clearly the layering effect of the newly poured oil over the surface of the oil that had already been in place. After 24 gallons of crude oil had been deposited, it was concluded that the objective of the crude oil spreading test in broken ice cover had been met. The test clearly indicated that the equilibrium thickness of this crude spilled in broken ice cover could be highly variable, most likely being a function of the oil properties, the environmental conditions, the concentration of the broken ice, and the size distribution of the ice pieces.

The elimination of ice for the open water spreading test allowed the use of a simplified testing technique. The open water technique consisted of submerging a cylindrical container from which both the top and bottom had been removed into the water, adding oil to the inside of the container such that it was contained within it, and then slowly removing the container from the surface of the water thereby allowing the oil to spread. Figure 16 is a photograph of the crude oil open water spreading test taken just prior to release of the oil by lifting the container which has an open top and bottom. Figure 17 is a photograph of the resulting oil slick taken moments after the container had been removed. Apparently some slight horizontal velocity was imparted to the oil slick as the container was removed, since Figure 17 shows the oil slick approaching the side wall of the basin. It is interesting to note that shortly after this photograph was taken, the slick literally bounced off the side wall without wetting the wall surface and returned toward the middle of the basin. The bulk of the spreading action occurred very quickly, with the area of the slick increasing only a very slight amount over an extended period of time after the initial spreading took place. The average equilibrium thickness of this crude oil slick in cold open water was measured as 0.73 cm, excluding the edges of the slick. The thickness, at the edges, of course, diminished. Figure 18 is a photograph of the edge of the slick after a period of time, showing the thinning of the slick at the boundaries and the effect of the volatiles coming off the surface of the slick.

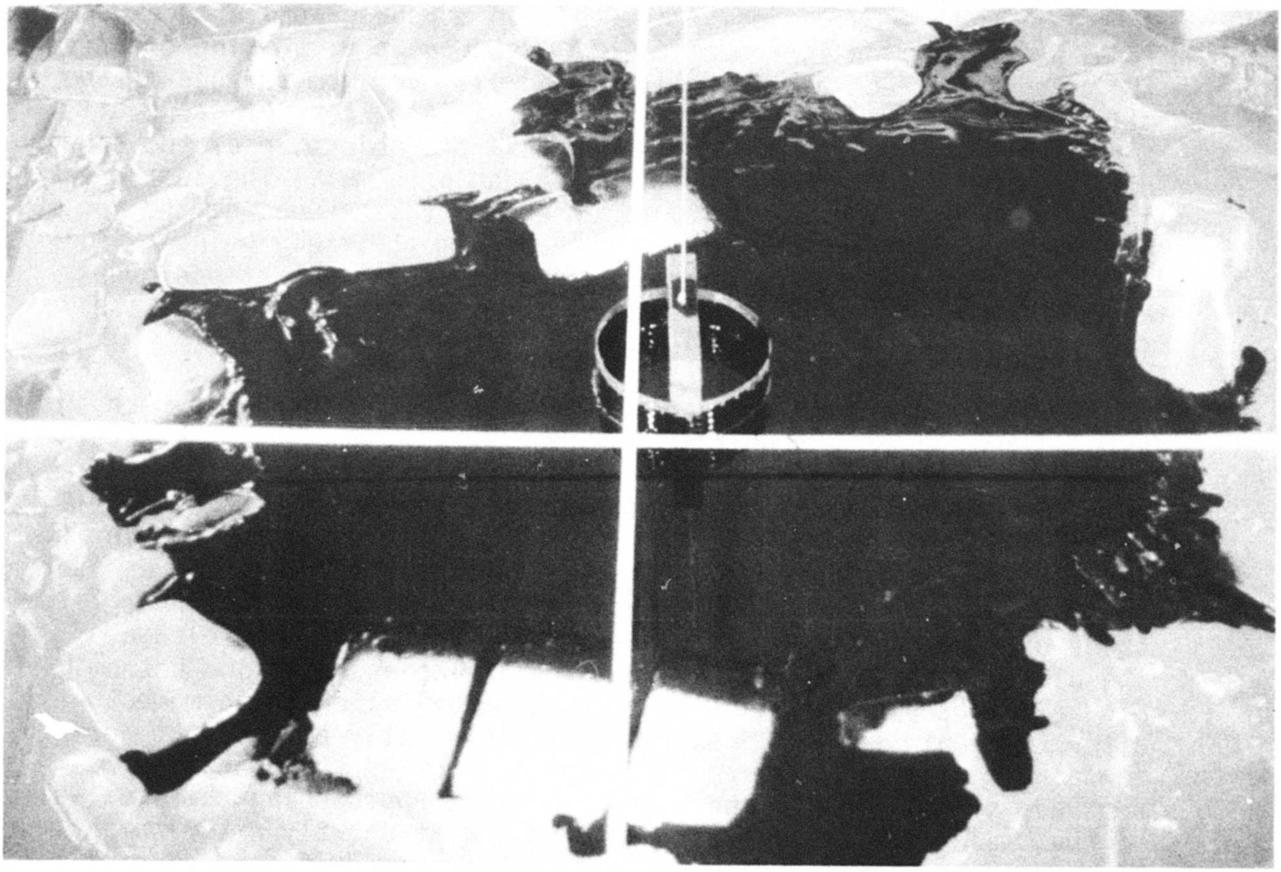


FIGURE 14. PHOTOGRAPH OF THE CRUDE OIL SPREADING TEST IN ICE AFTER TWENTY-FOUR GALLONS HAD BEEN DEPOSITED.

FIGURE 15. PHOTOGRAPH OF THE CRUDE OIL SPREADING TEST IN ICE SHOWING THE LAYERING EFFECT OF TWELVE GALLONS BEING ADDED TO TWELVE GALLONS PREVIOUSLY DEPOSITED.

FIGURE 16. PHOTOGRAPH OF THE CRUDE OIL OPEN WATER SPREADING TEST JUST PRIOR TO RELEASE OF THE OIL .

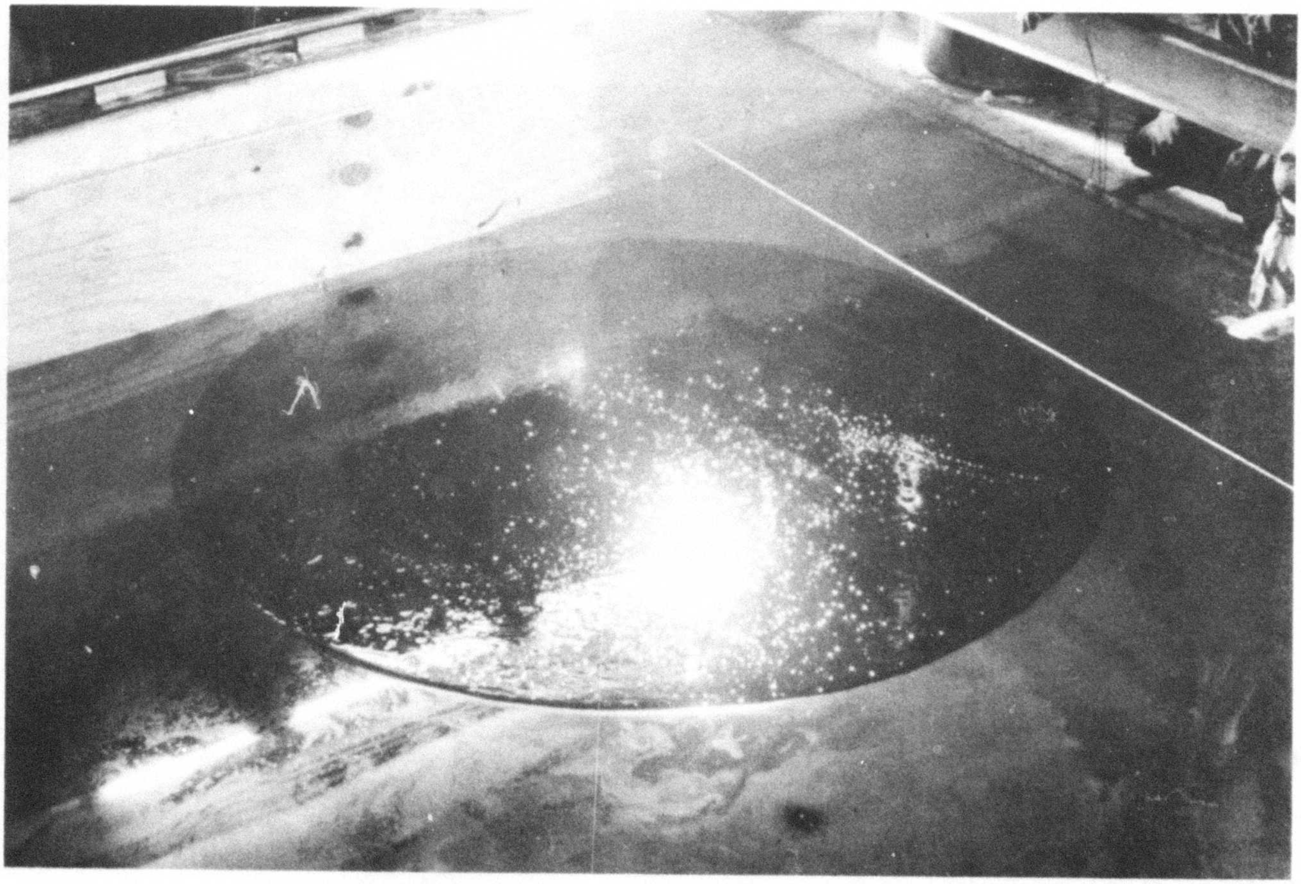


FIGURE 17. PHOTOGRAPH OF THE CRUDE OIL OPEN WATER SPREADING TEST TAKEN MOMENTS AFTER RELEASE OF THE OIL.

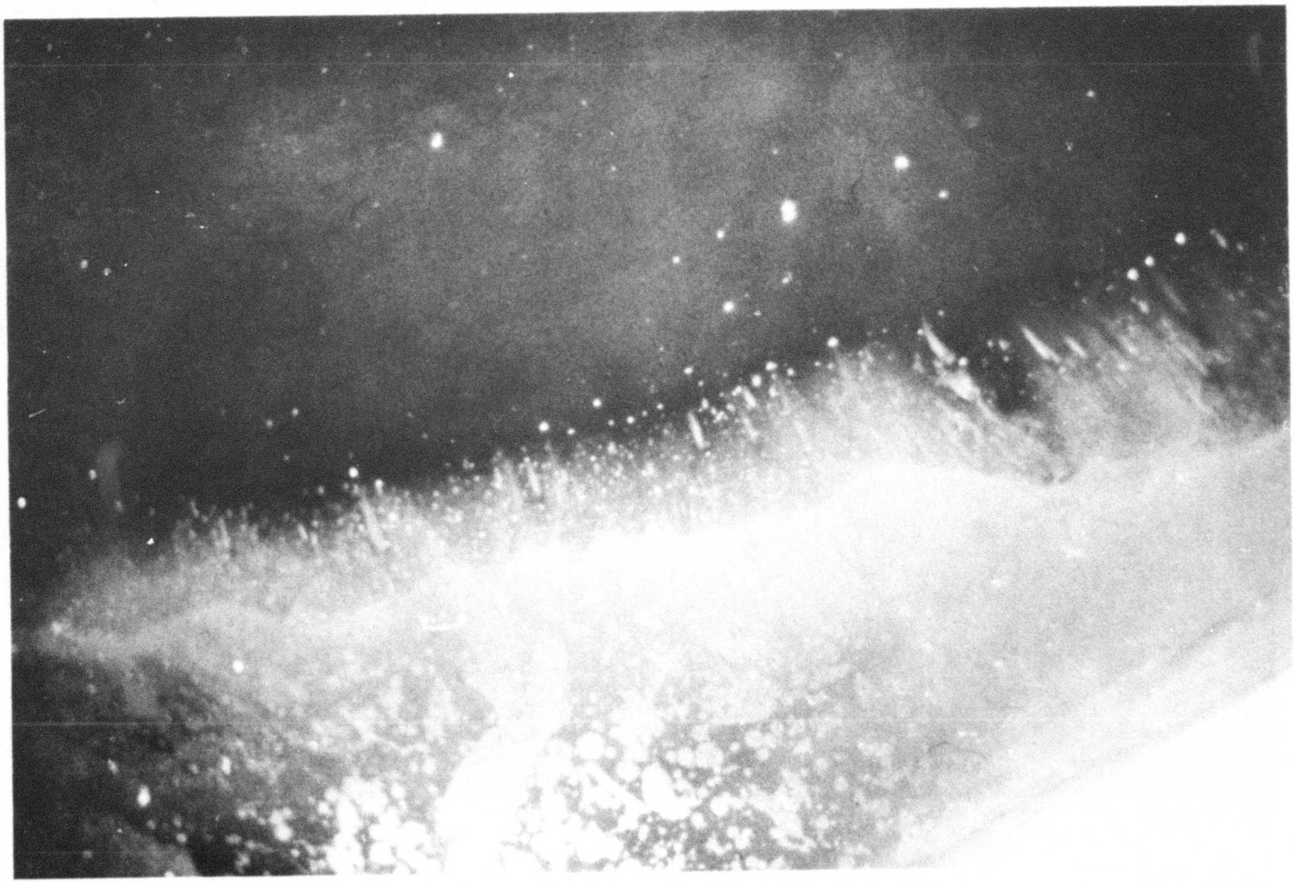


FIGURE 18. PHOTOGRAPH OF THE EDGE OF THE SLICK TAKEN DURING THE CRUDE OIL OPEN WATER SPREADING TEST.

The project plan called for the tests of the oil recovery devices to be conducted at two oil slick thicknesses. Tests were to be conducted in a nominal oil slick thickness of one-half inch so that the Phase II test results could be compared and related to the Phase I test program. The second nominal oil slick thickness was designated as the minimum natural equilibrium thickness, which the oil would attain under natural conditions in the test environment. It was anticipated that this minimum thickness could actually be four different minimum thicknesses, one each for crude oil in ice-infested waters, crude oil in open water, No. 2 fuel oil in ice-infested waters, and No. 2 fuel oil in open water. The primary objective of the spreading test sequence was to define these minimum thicknesses. At the conclusion of the crude oil spreading tests then, the value of minimum thickness to be used for open water tests with crude oil was clearly established as 0.73 cm. In the case of crude oil in ice-infested waters however, the choice of the minimum thickness was not so obvious, based upon the results of the crude oil spreading test in broken ice cover. Since the spreading test showed that the equilibrium thickness would likely be dependent upon the ice concentration and size of the ice pieces, resulting in the possibility of equilibrium oil slick thicknesses reaching several inches, a modification of the rationale for the selection of the minimum thickness for the crude oil recovery tests was required. Generally speaking, the major problems associated with oil spill clean-up are related to thin slick situations. In the case of very thick slicks of oil, of the order of several inches, recovery can easily be accomplished until the slick becomes very thin through the use of direct suction on the slick itself without the incorporation of any particular oil slick recovery hardware. For example, if a major spill of crude oil occurred in broken ice cover of sufficient thickness such that the resulting thickness of the oil slick was six inches, much of this oil could conceivably be recovered through the simple mechanism of inserting a suction hose directly into the oil and pumping it to the recovery barge. When the oil slick thickness diminishes to the point where the direct suction process results in the recovery of a significant amount of water along with the oil, the use of oil spill recovery devices which have a good oil recovery efficiency is then required. Based on this reasoning then, it is the thin slick situation where the oil recovery devices are most necessary, rather than the thick slick applications. In selecting the proper oil slick thickness for use in the crude oil portion of the program conducted in broken ice cover, the scenario was developed as being a situation where an open water slick encounters a flow of broken ice pieces resulting in a mixture of broken ice and oil which initially had the nominal open water equilibrium thickness of 0.73 cm. This thickness was therefore selected as the nominal oil slick thickness for the entire crude oil portion of the oil recovery

device test program, both the open water portion and the ice-infested waters portion.

The results of the spreading tests conducted with No. 2 fuel oil were quite different from those obtained in the crude oil tests. Since No. 2 fuel oil was expected to spread much more readily than the crude oil, a smaller initial volume was selected for use in the test, thereby allowing the open container technique to be used for both the open water tests and the ice-infested water test. The procedure used for No. 2 fuel oil was similar to that employed in the open water crude oil test, however, a smaller container was used. The quantity of oil selected for the fuel oil test increment was one gallon. In the case of No. 2 fuel oil, the open water spreading test was conducted first. After the container was immersed in the basin, one gallon of No. 2 fuel oil was poured into the container, after which the container was slowly removed from the basin. Visual rough estimates were made of the spreading rate of the fuel oil. The slick diameter had increased to about 7 feet in 20 seconds after release, increasing to 10 feet after 40 seconds, and a rectangular 12 feet by 14 feet after 60 seconds. The 12-foot limitation on the slick width was imposed by the width of the model basin. After 115 seconds, the slick covered a 12-foot by 17-foot area, indicating that the average slick thickness was in the neighborhood of 0.2 millimeters. Had the slick not been contained by the walls of the basin, and also, to some extent, by a residual sheen of oil left on the water surface from the crude oil tests, it is conceivable that the thickness would have been even less at this point in time. Since the 0.2 millimeter thickness was judged to be less than that practical for the conduct of the oil spill recovery test program, the spreading test in open water was concluded at that point.

The spreading test of No. 2 fuel oil in ice-infested waters was conducted in the same manner as the open water test by releasing a one-gallon quantity of oil from the cylindrical container having an open top and bottom. The spreading was very rapid, with the oil rapidly traveling through the spaces between the floating ice pieces. Again, the oil eventually reached the boundaries of the test facility. Consequently, it was concluded that the natural oil slick thickness for No. 2 fuel oil under these conditions would be less than that representing a practical value for the conduct of the oil spill recovery test program. Since this conclusion held for both the open water and ice-infested water cases, the decision was made to use the same nominal oil slick thickness for the No. 2 fuel oil tests as had been established for the crude oil tests so that tests conducted in these two types of oil would be directly comparable.

In summary, these simple spreading tests demonstrated the wide variation in natural oil slick thickness that may be encountered in the field. In the case of very thin oil, such as the No. 2 fuel oil tested in this program, the natural spreading thickness is quite thin, whether the slick be in open water or in ice-infested waters. The 0.2 millimeter thickness attained at the point at which the spreading tests were concluded is not necessarily felt to be the minimum thickness that would be achieved had the boundaries and other imperfect test conditions not been present. In all likelihood, the No. 2 fuel oil would continue spreading to a monomolecular thickness. For heavier oils however, such as the very viscous crude oil tested in this program, the presence of broken ice substantially changes the natural slick thickness attained by the oil. The natural slick thickness attained by the crude oil in cold open water was 0.73 cm. The natural slick thickness which can be attained in broken ice cover, likely a function of the concentration of the broken ice cover and the size distribution of the ice pieces, has been demonstrated to be several inches.

Summary of Oil Recovery Test Data

While there were several special purpose, or relatively non-repetitive, tests conducted during the course of this program, the bulk of the test program consisted of a series of basically similar tests. The data for these tests, classified as oil recovery tests, are summarized in tabular form in this section of the report and analyzed in detail in subsequent sections of the report. The test results obtained during the course of this program are both qualitative and quantitative in nature. The tabulations contained in this section summarize both types of test results. The quantitative data is separated into two groups; pre-test data, which includes all measurements of oil properties and environmental conditions existent prior to the test, and post-test data, which includes all oil property data and oil recovery data obtained during and following the test. The summary tabulations of the qualitative results of the program consist of condensations of notations made in the project log book of any particular occurrances or observations that were felt to be significant to the test program objectives.

Table 4 summarizes the pre-test data collected prior to tests conducted with the oil recovery devices operating in crude oil. In gathering the pre-test data, samples of oil were removed from the surface of the water and the oil properties measured. These properties include the specific gravity, viscosity, surface tension, and emulsification of the oil. Because of the agitation of the oil/ice/water mixture, and the heaviness of the crude oil, it was noted that water easily became encapsulated in the oil slick. This parameter

Date (1975)	Applicable Tests	Specific Gravity of Oil (Temp.,°C)	Viscosity of Oil, cps (Temp., °C)	Surface Tension of Oil, dpc (Temp.,°C)	Emulsificatio of Oil, %
10/1	Spreading - Ice	0.898 (0.5)	22,000 (0.2)	34.1 (0.1)	0
10/2	Spreading - OW	0.898 (0.5)	22,000 (0.5)	34.1 (0.1)	0
10/3	1, 2	0.899 (2.4)	16,770 (3.3)	35.2 (2.5)	0.05
10/6	3, 5	0.903 (2.0)	25,800 (2.1)	40.2 (1.4)	0.4
10/7	7, 8	0.9085 (0.5)	32,200 (-0.67)	53.2 (0.5)	1.0
10/8	9, 10	0.920 (-0.6)	25,200 (-0.38)	43.2 (-0.6)	0.5
10/9	11, 12	0.9365 (-1.25)	66,100 (-1.4)	42.7 (-0.6)	0.5
10/10	13, 14	0.931 (-0.25)	8,400 (0.93)	38.8 (0.4)	1.2
10/13	16	0.928 (-0.7)	22,600 (-0.55)	39.7 (-0.5)	0
10/15	18, 19	0.927 (-0.55)	53,800 (-0.65)	38.1 (-0.6)	0.8
10/16	20,21,22,23	0.908 (1.0)	67,600 (1.0)	36.6 (0.9)	0.5
10/20	24, 25	0.926 (-0.4)	43,600 (-0.4)	43.4 (-0.4)	0
10/21	26,27,28	0.931 (1.4)	48,300 (1.45)	38.8 (1.4)	0.5
10/23	29,30,31	0.928 (-0.25)	35,100 (-0.3)	43.0 (-0.4)	0
10/30	38	0.936 (1.15)	49,300 (1.45)	37.6 (1.4)	0

TABLE 4

PRE-TEST DATA FOR TESTS IN CRUDE OIL

ation %	Oil Encapsulation of Water, %	Nominal Oil Thickness, cm	Oil Thickness Between Ice, cm	Oil Temp., °C	Air Temp., °C	Ice Temp., °C	Ice Coverage, %	Typical Ice Cake Size,
	0	N/A	N/A	0.1	2.5	0.01	95	11x11x10
	0	N/A	N/A	0.1	2.5	N/A	0	N/A
	5	1.27	N/A	3.65	1.95	N/A	0	N/A
	15	0.73	N/A	3.05	1.57	N/A	0	N/A
	12	0.73	3.8	0.68	1.7	0	95	11x11x10
	15	0.73	3.0	-1.3	0.5	0	95	11x11x10
	16	0.73	3.0	-1.03	-0.25	0	95	11x11x10
	15	0.73	3.0	-1.1	-0.1	0	95	11x11x10
	15	0.73	3.8	-0.08	-0.28	-0.05	95	11x11x10
	15	0.73	3.8	-0.55	-0.4	-0.1	95	11x11x10
	15	0.73	3.2	-0.4	1.1	0.1	95	11x11x10
	20	1.27	4.4	0.2	-1.8	0.1	90	10x10x9
	10	1.27	5.4	-0.3	-1.8	-0.1	90	10x10x9
	15	0.73	3.8	-0.2	-0.8	-0.2	90	10x10x9
	20	0.73	3.2	-0.5	-1.8	-0.2	85	10x10x9

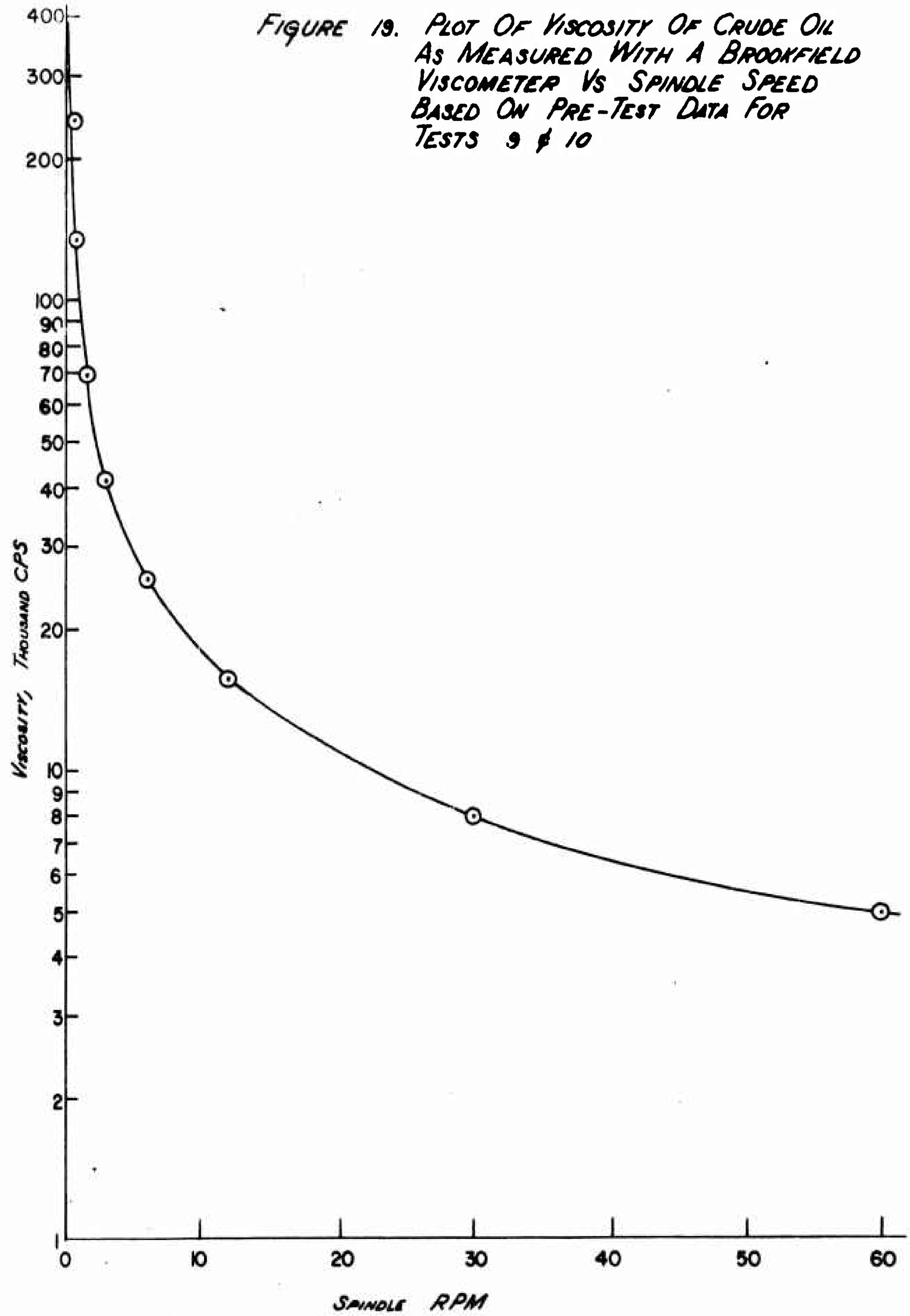
2

Oil Temp., °C	Air Temp., °C	Ice Temp., °C	Ice Coverage, %	Typical Ice Cake Size, in.	Ice Salinity, ppt	Absorption of Oil by Ice, %	Water Salinity, ppt	Water Temp., °C
0.1	2.5	0.01	95	11x11x10	0	N/A	0.08	1.5
0.1	2.5	N/A	0	N/A	N/A	N/A	0.08	2.9
3.65	1.95	N/A	0	N/A	N/A	N/A	1.0	4.15
3.05	1.57	N/A	0	N/A	N/A	N/A	1.1	4.3
0.68	1.7	0	95	11x11x10	0	1.0	0.9	-0.05
-1.3	0.5	0	95	11x11x10	0	0.75	0.9	-1.4
-1.03	-0.25	0	95	11x11x10	0	1.0	0.4	-0.77
-1.1	-0.1	0	95	11x11x10	0	0.5	0.8	-0.6
-0.08	-0.28	-0.05	95	11x11x10	0	0	0.03	-0.05
-0.55	-0.4	-0.1	95	11x11x10	0	0.5	0	-0.45
-0.4	1.1	0.1	95	11x11x10	0	0	0	-0.3
0.2	-1.8	0.1	90	10x10x9	0	0	0.07	0.3
-0.3	-1.8	-0.1	90	10x10x9	0.08	0	0.07	0
-0.2	-0.8	-0.2	90	10x10x9	0.05	0	0.07	-0.2
-0.5	-1.8	-0.2	85	10x10x9	0	0	0.05	-0.4

was then added to the pre-test data list. The encapsulated water was measured after a sample skimmed from the surface of the basin had been allowed to separate by gravity forces at room temperature. Emulsified water was defined as that volume of water removed by centrifuging a sample of collected oil after it had been allowed to separate by gravity forces at room temperature. The value of nominal oil thickness defines the target value established for each particular test , where the nominal thickness is defined as that thickness of oil spread over the entire surface area of the model basin without regard to the effect of the broken ice pieces. Also recorded was the actual oil thickness between ice pieces as measured with the oil thickness probe. The temperature of the oil comprising the oil slick, the temperature of the air just above the oil surface, and the temperature of the water just below the oil surface were measured with precision thermometers. The ice temperature was measured by crushing a piece of ice in a container and then inserting a thermometer. The ice coverage and the typical ice cake size are both estimates. The salinity of the ice was measured in the same manner as the water salinity was measured after melting an ice sample. The absorption of oil by the ice was determined by removing a random sample of ice from the basin, melting it, and then measuring the resulting volumes of oil and water.

Briefly reviewing the information in each column of Table 4, it is noticed that the specific gravity of the crude oil varies over the course of the program in a somewhat random manner, but generally increasing as the program proceeds. This general trend would be expected since the volatiles continue to escape from the oil as the oil ages. The variation during the course of the program is, to some degree, likely due to the replenishment of oil from test to test. In some cases this replenishment process was accomplished with oil that had been used in a previous test, and in other cases with fresh crude oil. The viscosity of the crude oil is seen to be quite high and quite variable through the course of the program. In fact, this column might more accurately be termed the apparent viscosity of the oil as measured by a Brookfield viscometer at a spindle speed of rotation of 6 rpm. A single value of the viscosity for the crude oil used in this Phase II program could not be obtained. The oil exhibited a thixotropic property, whereby the viscosity varied with shear rate. The first indication of the thixotropic property of the crude oil was given during the first spreading test with crude oil in broken ice cover. As previously described, the freshly poured oil tended to flow over the top of the oil that was already in place and in a stationary mode, rather than the new oil mixing with the oil already in place. The value given in Table 4 for the viscosity of the crude oil is therefore an arbitrary selection at a convenient spindle speed for the Brookfield viscometer. Figure 19 is a plot of measured

FIGURE 19. PLOT OF VISCOSITY OF CRUDE OIL AS MEASURED WITH A BROOKFIELD VISCOMETER VS SPINDLE SPEED BASED ON PRE-TEST DATA FOR TESTS 9 & 10



viscosity versus the spindle speed of the Brookfield viscometer based on the data recorded for Tests 9 and 10. Since the Brookfield viscometer measures viscosity by measuring the drag on a rotating cylinder immersed in the oil being tested at various speeds, for Newtonian fluids and a single spindle diameter, the viscosity reading should be identical for all values of spindle speed. Figure 19 shows this clearly not to be the case for the crude oil used in this test program, with the numerical value of viscosity obtained varying over a range of almost two orders of magnitude. To aid in interpreting the test results, it may be helpful to point out that the oil seen by the oil recovery devices was in a stationary mode, consequently, the viscosity of the oil as the oil recovery devices encountered it could be thought of as being in the range of 400,000 centipoise, the value taken at a spindle speed of zero rpm from Figure 19. This non-Newtonian property of the crude oil used in the Phase II program must be borne in mind in interpreting all of the crude oil tests of the program.

Recalling that the crude oil acquired for the Phase II program was obtained from the same source as that used in the Phase I test program, it should be pointed out that the non-Newtonian behavior of the crude was not detected during the Phase I program, and, in addition, the values of viscosity measured during the Phase I program were substantially less, being in the order of 1,000 to 11,000 centipoise. In retrospect, it appears that a time and cost saving procedure used in the Phase I program resulted in a significant change in the physical properties of the crude oil. In the Phase I program, tests were conducted initially in No. 2 fuel oil. At the conclusion of the fuel oil portion of the program, the oil was removed, and the remaining ice was cleaned to the greatest extent possible short of disposing of all ice and draining and cleaning the basin entirely before switching to crude oil. As a result of this procedure, apparently sufficient fuel oil was left on the units being tested, on the ice pieces, on the surface of the model basin, and behind the protective barriers to significantly cut the crude oil. Rough calculations indicate that a 10% to 15% mixture of the fuel oil with the crude oil could result in such a reduction in the oil viscosity. It is conceivable that residual amounts of fuel oil of this magnitude could have remained in the test system in spite of the clean-up effort. In contrast to the Phase I program sequence, the Phase II program called for initial testing to be done in crude oil with the testing in fuel oil scheduled after the completion of the crude oil tests. The reason for changing the testing sequence in Phase II was to make the final clean-up operations somewhat less difficult by having fuel oil to clean up rather than crude oil. As a result, the crude oil in the Phase II program was deposited on a perfectly clean water surface

witn perfectly clean sidewalls and equipment. Consequently, there was no possibility of a change in crude oil properties due to the testing procedure or testing sequence in the Phase II program.

Returning to a discussion of the pre-test data of Table 4, the surface tension is seen to range from about 34 to 53 dpc. This is somewhat greater than the range measured for the crude oil in Phase I, which ranged from 29 to 39 dpc. The emulsification of the oil prior to testing was maintained at a low value throughout the test program, generally under one percent. After being recovered in a test, the oil was allowed to settle at room temperature, after which the oil and the settled water were separately removed and measured. As a result, the oil that was reused for subsequent tests had most of the water removed from it. As previously indicated, the heavy crude oil had a tendency to encapsulate some water within it. The encapsulated water volume typically ran about 15%.

Oil recovery tests were conducted in crude oil at two values of nominal oil thickness, a value of 0.73 cm, the value determined from the crude oil spreading tests previously described, and a value of 1.27 cm, or 0.5 inches, corresponding to one of the test conditions of the Phase I program. The value of oil thickness between ice pieces tabulated in Table 4 is a typical value rather than a uniformly measured value. The Phase II crude oil was of such a heavy consistency that it did not tend to redistribute itself in a uniform manner throughout the model basin as would lighter oils. A substantial effort was made to groom the oil/ice field for each day's testing such that the oil distribution would be as uniform as possible. However, an absolutely uniform distribution could never be attained. With the exception of the open water test cases, the oil, air, ice, and water temperatures were maintained close to 0°C. In the case of the open water tests, Tests 1 through 5, the heat influx through the bottom of the model basin apparently resulted in an increase in the water temperature, which is subsequently seen as an increase in the oil temperature and the air temperature just above the oil surface. Any attempt to add ice for additional cooling of the water at that point in the test program would have required the agitation of the water to obtain a uniform temperature distribution, which subsequently would have destroyed the uniform oil test condition. Because of this, the slight error of 3 to 4°C in the temperature of the oil and water was accepted.

The estimated concentration of ice pieces ranged in the neighborhood of 90% to 95% coverage. The typical ice piece size did not change to any great extent during the test program since additional ice was added as conditions warranted. Since both fresh water ice and fresh water were used throughout the entire Phase II program, the ice and water salinity were close to zero

throughout. Also, because of the hard fresh water ice, there was very little absorption of oil by the ice. The only absorption observed was in areas of the ice that had air bubbles entrapped during the freezing process resulting in a relatively porous area.

Table 5 is a summary of the post-test data for the oil recovery tests conducted in crude oil. In the case of the speed of advance, the speed of Lockheed drum rotation, and the linear speed of the Marco belt, both the target speed established for the test and the actual measured speed are tabluated. In general, the speed of advance could be preset with a fair degree of accuracy with the basin carriage drive system, however, there were slight variations due to interaction with the broken ice field. In a similar manner, the speed of the Marco belt could be fairly accurately preset. In contrast to these however, it was difficult to accurately preset the rotational speed of the Lockheed drum. For a given setting of the hydraulic drive system, the Lockheed drum would operate at one speed in air, at a lesser speed in water, at a still lesser speed depending upon the amount of oil loading of the unit, and with additional speed variations caused by impact with broken ice pieces. As a result, the speed of the Lockheed drum often varied significantly over the length of a run. The speed tabulated in the actual speed column is, therefore, an average measured over the length of the run based upon counting the number of revolutions made by the drum and dividing by the time of the run. The speed variation problems experienced with the Lockheed drum are felt to be a result of the inadequate power developed by the Marco power supply system when applied to powering the Lockheed oil recovery device.

Also tabulated in Table 5 are the length of each test run; the time of each run; the total volume recovered, including both the volume of oil and the volume of water; the total recovery rate, consisting of the preceeding data divided by the time of the run; the oil volume recovered, consisting of only the net volume of oil; the oil recovery rate; the oil recovery efficiency, defined as the net volume of oil recovered divided by the total volume of oil, water and ice recovered; the oil volume encountered, which is a theoretical value calculated on the basis of the nominal oil thickness, the effective width of the oil recovery device, and the length of the run; the throughput efficiency, defined as the ratio of the net oil volume recovered divided by the theoretical oil volume encountered; and the properties of the recovered oil, including the specific gravity, the viscosity, the surface tension and the emulsification. While the definition of the throughput efficiency employed here is the standard definition, it should be qualified when applied to the performance of oil recovery devices operating in ice infested waters.

Date (1975)	Test No.	Device	Tar. Speed of Advance fps	Tar. Speed of Belt, fps, Drum, rpm	Act. Speed of Advance fps	Act. Speed of Belt, fps, Drum, rpm	Length of Run, feet	Time of Run, sec.	Tot Rec
10/3	1	Marco	0.5	4	0.50	4	29.3	58.4	
10/3	2	Lockheed	0.5	8	0.51	6.3	34.6	67.8	
10/6	3	Marco	0.5	4	0.51	4	40.5	79.0	
10/6	5	Lockheed	0.5	8	0.51	12.2	71.7	140.0	
10/7	7	Marco	0.5	4	0.51	4	36.2	71.0	
10/7	8	Lockheed	0.5	8	0.50	6.25	33.0	66.0	
10/8	9	Marco	0.5	4	0.49	4	37.6	77.4	
10/8	10	Lockheed	0.5	8	0.51	6.5	39.0	67.0	
10/9	11	Marco	0.5	4	0.49	4	33.6	69.0	
10/9	12	Lockheed	0.5	8	0.51	6.9	40.6	78.8	
10/10	13	Lockheed	1.0	8	1.00	7.3	38.8	38.0	
10/10	14	Lockheed	1.5	8	1.43	7.2	35.6	24.9	
10/13	16	Marco	0.5	4	0.47	4	41.4	88.6	
10/13	18	Marco	0.5	4	0.48	4	46.8	98.2	
10/15	19	Lockheed	0.5	13	0.50	11.5	42.7	84.6	
10/16	20	Marco	0.5	4	0.34	4	28.5	84.0	
10/16	21	Marco	0.5	4	0.49	4	36.4	74.2	
10/16	22	Marco	0.5	1	0.49	1	55.0	112.0	
10/16	23	Marco	1.5	4	1.16	4	34.9	30.0	
10/20	24	Marco	0.5	4	0.47	4	33.5	71.2	
10/20	25	Lockheed	0.5	8	0.49	6.3	42.2	86.3	
10/21	26	Oil Mop	0	0.15	0	0.15	NA	1020.0	
10/21	27	Oil Mop	0	0.15	0	0.15	NA	845.0	
10/21	28	Oil Mop	0	0.15	0	0.15	NA	3600.0	
10/23	29	OSI	1.35	NA	1.68	NA	37.3	22.2	
10/23	30	JBF	0.5	NA	0.58	NA	41.0	71.0	
10/23	31	JBF	SP	NA	0	NA	0	NA	
10/30	38	Lockheed	0.5	3	0.65	2.7	43.7	67.4	

TABLE 5

POST-TEST DATA FOR TESTS IN CRUDE OIL

al Volume overed,gal.	Total Recovery Rate, gpm.	Oil Volume Recovered, gal.	Oil Recovery Rate, gpm.	Oil Recovery Efficiency,%	Oil Volume Encountered,gal.	Throughput Efficiency,%	Specific Gravity of Oil	(Temp,°C)
30.9	31.7	9.8	10.1	32	9.9	99	0.9073	(- 1.0)
24.6	21.8	17.5	15.5	71	76.7	23	0.9073	(1.0)
20.2	15.3	9.2	7.0	46	7.8	118	0.913	(- 0.2)
92.5	39.6	57.3	24.6	62	91.4	63	0.912	(- 0.1)
11.3	9.5	2.1	1.8	19	7.0	30	0.945	(- 0.4)
10.4	9.5	5.2	4.7	50	42.1	12	0.9355	(- 1.65)
7.3	5.7	1.9	1.5	26	7.3	26	0.925	(- 1.35)
8.8	6.9	2.5	1.9	28	49.7	5	0.931	(- 0.9)
8.3	7.2	2.5	2.2	30	6.5	38	0.932	(- 0.9)
11.7	8.9	4.8	3.7	41	51.7	9	0.932	(- 0.8)
5.6	8.8	2.9	4.6	52	49.5	6	0.930	(0.6)
5.0	12.0	1.5	3.6	30	45.4	3	0.9305	(0.55)
18.7	12.7	2.5	1.7	13	8.0	31	0.930	(1.4)
27.3	16.7	2.5	1.5	9	9.1	28	0.9275	(- 0.5)
33.8	24.0	9.7	6.8	29	54.4	18	0.905	(0.5)
14.7	10.5	2.5	1.8	17	5.5	46	0.9095	(1.35)
21.8	17.7	2.5	2.0	12	7.1	36	0.9225	(- 1.1)
10.1	5.4	5.5	2.9	54	10.7	51	0.920	(- 0.8)
12.4	24.8	5.9	11.8	47	6.8	87	0.921	(- 0.9)
24.4	20.5	6.1	5.1	25	11.3	54	0.9205	(0.4)
16.4	11.4	8.4	5.8	51	93.7	9	0.921	(0.4)
16.4	1.0	16.0	0.9	97	5.3	300	0.925	(3.2)
8.8	0.6	8.4	0.6	95	NA	NA	0.930	(1.25)
35.3	0.6	34.0	0.6	96	3.1	1112	0.931	(1.65)
30.8	83.2	0.8	2.3	3	15.6	5	0.9305	(1.05)
25.6	21.6	7.6	6.4	30	15.3	49	0.930	(1.0)
0	0	0	0	0	0	NA	NA	(NA)
7.1	6.4	5.9	5.2	82	55.7	11	0.937	(1.9)

il Recovery fficiency,%	Oil Volume Encountered,gal.	Throughput Efficiency,%	Specific Gravity of Oil	(Temp,°C)	Viscosity of Oil, cps	(Temp,°C)	Surface Tension of Oil,dpc	(Temp,°C)	Emulsification of Oil, %
32	9.9	99	0.9073	(- 1.0)	16,700	(- 1.1)	39.9	(- 1.05)	1.75
71	76.7	23	0.9073	(1.0)	16,048	(0.95)	38.4	(1.0)	1.5
46	7.8	118	0.913	(- 0.2)	38,900	(- 0.43)	43.4	(- 0.6)	0.5
62	91.4	63	0.912	(- 0.1)	39,000	(- 0.50)	42.0	(- 0.5)	0.5
19	7.0	30	0.945	(- 0.4)	8,400	(- 0.55)	39.8	(- 0.2)	5.5
50	42.1	12	0.9355	(- 1.65)	30,400	(- 1.8)	37.4	(- 1.8)	2.0
26	7.3	26	0.925	(- 1.35)	43,900	(- 1.27)	37.4	(- 0.4)	2.0
28	49.7	5	0.931	(- 0.9)	42,500	(- 1.2)	39.2	(- 0.6)	1.5
30	6.5	38	0.932	(- 0.9)	35,300	(0.3)	40.6	(0.35)	2.0
41	51.7	9	0.932	(- 0.8)	48,200	(- 0.8)	40.5	(- 0.95)	1.0
52	49.5	6	0.930	(0.6)	43,400	(0.78)	37.3	(0.7)	1.75
30	45.4	3	0.9305	(0.55)	43,400	(0.77)	38.3	(0.35)	2.5
13	8.0	31	0.930	(1.4)	42,100	(1.35)	36.7	(1.45)	2.0
9	9.1	28	0.9275	(- 0.5)	67,000	(- 0.55)	35.6	(- 0.5)	2.75
29	54.4	18	[illegible]	(0.5)	32,800	(0.55)	35.2	(0.5)	2.0
17	5.5	46	[illegible]	(1.35)	31,900	(1.5)	36.6	(1.5)	3.0
12	7.1	36	0.9[illegible]25	(- 1.1)	67,000	(- 1.2)	35.9	(- 1.25)	3.0
54	10.7	51	0.920	(- 0.8)	68,600	(- 0.95)	36.4	(- 0.9)	3.0
47	6.8	87	0.921	(- 0.9)	66,800	(- 0.85)	36.7	(- 0.8)	2.5
25	11.3	54	0.9205	(0.4)	33,200	(0.4)	39.7	(0.4)	1.5
51	93.7	9	0.921	(0.4)	33,200	(0.4)	37.6	(0.4)	0.5
97	5.3	300	0.925	(3.2)	18,700	(3.6)	33.3	(3.5)	1.0
95	NA	NA	0.930	(1.25)	21,400	(1.5)	33.5	(1.4)	1.0
96	3.1	1112	0.931	(1.65)	17,300	(1.9)	33.2	(1.8)	1.0
3	15.6	5	0.9305	(1.05)	31,600	(1.15)	33.5	(1.1)	1.0
30	15.3	49	0.930	(1.0)	29,800	(1.2)	33.8	(1.1)	1.0
0	0	NA	NA	(NA)	NA	(NA)	NA	(NA)	NA
82	55.7	11	0.937	(1.9)	15,700	(2.0)	35.8	(2.2)	1.5

3

The throughput efficiency is commonly interpreted as a measure of how much of the oil encountered by the oil recovery device is actually collected by it. In the case of ice infested waters and oils of high viscosity, such as the crude oil used in the Phase II program, an oil recovery device that pushes the ice ahead of it rather than processing the ice as it is encountered will in all likelihood push the oil ahead of it along with the ice. Consequently, little oil gets to the unit, little can therefore be recovered, and the calculated throughput efficiency would be quite low. The argument has been put forward that the unit never encountered the oil in such a situation, however, in the most meaningful application of the throughput efficiency terminology, such an inability of the unit to get at, or encounter, the oil should in all justice be charged against that unit. The throughput efficiency as used in this report, therefore, is a measure of both the ability of the oil recovery device to get at oil interspersed between ice pieces and the ability of the unit to recover the oil that is actually encountered.

In comparing the oil properties measured before and after tests in Table 4 and 5 respectively, it is seen that few significant changes occurred in the oil properties as a result of the oil being recovered by the devices tested. The only change worthy of note is the change in the emulsification of the oil, which was generally less that 1% prior to a test, and typically ranged from 1% to 3% following a test.

Table 6 is a summary of the pre-test data gathered for the oil recovery tests conducted in No. 2 fuel oil. The data recorded in the fuel oil portion of the program is identical to that recorded in the crude oil portion. In reviewing the oil property data of Table 6, it is seen that very little variation was recorded in the specific gravity, viscosity, surface tension, and emulsification of the No. 2 fuel oil prior to testing. Of particular note is the consistency of the viscosity readings over the range of spindle speed available from the Brookfield viscometer. The Newtonian properties exhibited by the No. 2 fuel oil were in considerable contrast to the non-Newtonian properties exhibited by the Phase II crude oil. Also in contrast to the crude oil, there was no emulsification of the fuel oil, and, obviously, there was no encapsulation of water within the fuel oil. The light fuel oil separated out very rapidly from a water-oil mixture and the oil quickly distributed itself uniformly throughout the basin.

The post-test data obtained from the oil recovery tests conducted in No. 2 fuel oil are summarized in Table 7. The difficulty in maintaining a uniform speed of rotation of the Lockheed drum was reduced in the fuel oil portion of the program in comparison to that

Date (1975)	Applicable Tests	Specific Gravity of Oil (Temp.,°C)	Viscosity of Oil, cps (Temp.,°C)	Surface Tension of Oil, dpc (Temp.,°C)	Emulsificati of Oil, %
11/7	45, 46	0.861 (2.4)	7.3 (2.4)	29.6 (2.4)	0
11/10	47, 48	0.859 (2.7)	7.6 (2.7)	29.5 (2.7)	0
11/11	49, 50	0.861 (2.4)	7.3 (2.4)	29.6 (2.4)	0
11/12	51, 52, 53, 54	0.862 (2.3)	7.5 (2.3)	29.6 (2.3)	0
11/13	55, 56, 56A, 57, 58	0.861 (3.8)	7.6 (3.8)	31.3 (3.8)	0
11/14	59, 60, 61	0.861 (2.8)	7.7 (2.8)	31.3 (2.8)	0
11/17	62, 63	0.861 (2.4)	7.7 (2.4)	31.5 (2.4)	0
11/18	64, 65	0.861 (2.4)	7.7 (2.4)	31.4 (2.4)	0
11/19	66, 67	0.861 (2.5)	7.7 (2.5)	31.4 (2.5)	0

TABLE 6

PRE-TEST DATA FOR TESTS IN NO.2 FUEL OIL

...tion %	Oil Encapsulation of Water, %	Nominal Oil Thickness, cm	Oil Thickness Between Ice, cm	Oil Temp., °C	Air Temp., °C	Ice Temp., °C	Ice Coverage, %	Typical Ice Cake Size, in.
	0	1.27	N/A	2.5	-1.8	N/A	0	N/A
	0	0.73	N/A	0.4	-1.8	N/A	0	N/A
	0	0.73	3.2	-0.2	-0.8	-0.2	95	11x11x10
	0	0.73	3.2	-0.2	-1.3	-0.1	95	11x11x10
	0	0.73	3.2	-0.4	-1.3	-0.2	95	11x11x10
	0	1.27	4.4	-0.4	-1.8	-0.2	90	11x11x10
	0	0.73	3.2	-0.6	-1.8	-0.2	90	11x11x10
	0	0.73	3.2	-0.5	-1.8	-0.2	95	11x11x10
	0	0.73	3.2	-0.5	-1.8	-0.2	95	11x11x10

Oil Temp., °C	Air Temp., °C	Ice Temp., °C	Ice Coverage, %	Typical Ice Cake Size, in.	Ice Salinity, ppt	Absorption of Oil by Ice, %	Water Salinity, ppt	Water Temp., °C
2.5	-1.8	N/A	0	N/A	N/A	N/A	0.07	2.5
0.4	-1.8	N/A	0	N/A	N/A	N/A	0.07	0.4
0.2	-0.8	-0.2	95	11x11x10	0	0	0.07	2.3
0.2	-1.3	-0.1	95	11x11x10	0	0	0.07	0.2
0.4	-1.3	-0.2	95	11x11x10	0	0	0.07	-0.4
0.4	-1.8	-0.2	90	11x11x10	0	0	0.07	-0.4
0.6	-1.8	-0.2	90	11x11x10	0	0	0.07	-0.4
0.5	-1.8	-0.2	95	11x11x10	0	0	0.07	-0.3
0.5	-1.8	-0.2	95	11x11x10	0	0	0.07	-0.3

experienced in the crude oil portion of the program. While the variations in drum speed due to impact with the broken ice remained, variations in the loading of the drum due to oil coating the discs was not noticeable in the fuel oil tests.

In comparing the physical properties of the oil measured prior to and subsequent to a test run from Table 6 and Table 7 respectively, no significant changes in oil specific gravity, viscosity, or surface tension were detected. In the case of the emulsification of the oil, a measurement greater than zero was obtained in only three tests of the Marco device.

Tables 8 and 9 are summaries of the notations made during standard oil recovery tests conducted in crude oil and No. 2 fuel oil respectively.

Analysis of Open Water Tests

Table 10 is a summary of the oil recovery data obtained from the tests conducted in open water. Both the Lockheed and the Marco devices were tested in two oil slick thicknesses of crude oil and No. 2 fuel oil. The recovery and efficiency data were extracted from Tables 5 and 7. In interpreting the oil recovery rates obtained with the two oil recovery devices, it must be remembered that the width of the two devices differs considerably. The width of the Lockheed drum is 85.5 inches while the width of the Marco belt is 13.0 inches. Because of this considerable difference in the width of the units, the oil recovery results obtained are also presented on the basis of a unit oil recovery rate, defined as the oil recovery rate per unit width of the unit and having the units of gpm per foot. However, while a direct comparison of oil recovery rate is not entirely equitable because of the great difference in the width of the two devices, a comparison of the oil recovery rate per foot of width is likewise not totally equitable due to the varying effect of boundary conditions on the two devices. In particular, oil drawn in from beyond the width of the swath as the device travels down the length of the basin could be a significant factor. The boundary effects which might limit the oil drawn in from beyond the swath width would be expected to be much greater in the case of the wide Lockheed unit than they would be for the narrow Marco unit. With this qualification in mind, the oil recovery results will be presented as both oil recovery rate and unit oil recovery rate.

Date (1975)	Test No.	Device	Tar. Speed of Advance fps	Tar. Speed of Belt, fps, Drum, rpm	Act. Speed of Advance fps	Act. Speed of Belt, fps, Drum, rpm	Length of Run, feet	Time of Run, sec.
11/7	45	Marco	0.5	4	0.52	4	26.2	50.0
11/7	46	Lockheed	0.5	8	0.52	9.0	31.2	60.0
11/10	47	Lockheed	0.5	8	0.54	7.4	32.4	60.0
11/10	48	Marco	0.5	4	0.52	4	31.3	60.0
11/11	49	Marco	0.5	4	0.48	4	31.3	65.4
11/11	50	Lockheed	0.5	8	0.48	7.4	48.2	100.0
11/12	51	Marco	1.0	4	0.88	4	44.4	50.2
11/12	52	Marco	1.5	4	1.32	4	58.6	44.5
11/12	53	Lockheed	1.0	8	0.95	8.1	60.6	64.0
11/12	54	Lockheed	1.5	8	1.06	8.7	56.4	53.0
11/13	55	Marco	0.5	1	0.43	1.2	27.0	63.0
11/13	56	Marco	0.5	1.5	0.45	1.5	28.1	62.0
11/13	56A	Marco	0.5	2.5	0.48	2.5	28.4	59.0
11/13	57	Lockheed	0.5	3	0.51	2.8	31.4	61.8
11/13	58	Lockheed	0.5	13	0.51	11.0	48.8	96.2
11/14	59	Marco	0.5	4	0.49	4	29.4	60.0
11/14	60	Lockheed	0.5	8	0.52	7.5	32.0	62.0
11/14	61	Oil Mop	0	0.15	0	0.15	NA	3600.0
11/17	62	Marco	0.5	4	0.49	4	31.7	65.2
11/17	63	Lockheed	0.5	8	0.51	7.1	52.5	103.8
11/18	64	Marco	0.5	4	0.50	4	37.7	76.0
11/18	65	Lockheed	0.5	8	0.52	8.7	39.7	77.0
11/19	66	Marco	0.5	4	0.51	4	30.8	60.0
11/19	67	Marco	0.5	4	0.47	4	27.4	58.5

TABLE 7

POST-TEST DATA FOR TESTS IN NO. 2 FUEL OIL

Total Volume Recovered, gal.	Total Recovery Rate, gpm.	Oil Volume Recovered, gal.	Oil Recovery Rate, gpm.	Oil Recovery Efficiency, %	Oil Volume Encountered, gal.	Throughput Efficiency, %	Specific Gravit Oil	(Temp,
19.7	23.7	5.0	6.0	26	8.8	57	0.864	(3.5
38.2	38.2	37.4	37.4	98	69.3	54	0.859	(3.7
20.2	20.2	19.7	19.7	98	41.3	48	0.861	(2.7
21.8	21.8	6.7	6.7	31	6.1	111	0.8625	(3.2
16.4	15.0	6.7	6.2	41	6.1	111	0.8625	(2.2
24.4	14.6	23.5	14.1	97	61.4	38	0.862	(1.8
6.7	8.0	1.7	2.0	25	8.6	19	0.862	(2.3
8.4	11.3	2.5	3.4	30	11.4	22	0.862	(2.3
18.7	17.5	16.0	15.0	85	77.2	21	0.862	(2.3
13.9	15.7	11.8	13.3	85	71.9	16	0.862	(2.3
1.7	1.6	0.84	0.8	50	5.2	16	0.861	(3.8
2.9	2.8	1.05	1.02	36	5.4	19	0.861	(3.8
13.0	13.2	4.4	4.5	34	5.5	80	0.861	(3.8
4.2	4.1	4.2	4.1	100	40.0	10	0.861	(3.8
29.8	18.6	29.4	18.3	99	62.2	47	0.861	(3.8
9.2	9.2	5.5	5.5	59	9.9	55	0.861	(2.8
26.0	25.2	25.2	24.4	97	71.1	35	0.861	(2.8
5.0	0.08	5.0	0.08	100	7.7	65	0.361	(2.8
23.1	21.3	5.5	5.0	24	6.1	89	0.861	(2.4
28.6	16.5	28.6	16.5	100	66.9	43	0.861	(2.4
22.3	17.6	3.8	3.0	17	7.3	52	0.861	(2.4
27.7	21.6	27.7	21.6	100	50.6	55	0.861	(2.4
21.0	21.0	5.0	5.0	24	6.0	84	0.861	(2.5
19.7	20.2	3.8	3.9	19	5.3	71	0.861	(2.5

2

Oil Recovery Efficiency,%	Oil Volume Encountered,gal.	Throughput Efficiency,%	Specific Gravity of Oil	(Temp,°C)	Viscosity of Oil, cps	(Temp,°C)	Surface Tension of Oil, dpc	(Temp,°C)	Emulsification of Oil, %
26	8.8	57	0.864	(3.5)	7.93	(3.5)	32.0	(3.5)	0
98	69.3	54	0.859	(3.7)	7.20	(3.7)	31.9	(3.7)	0
98	41.3	48	0.861	(2.7)	7.50	(2.7)	29.6	(2.7)	0
31	6.1	111	0.8625	(3.2)	7.40	(3.2)	29.5	(3.2)	0
41	6.1	111	0.8625	(2.2)	7.30	(2.2)	29.6	(2.2)	0
97	61.4	38	0.862	(1.8)	7.45	(1.8)	31.1	(1.8)	0
25	8.6	19	0.862	(2.3)	7.50	(2.3)	29.6	(2.3)	0
30	11.4	22	0.862	(2.3)	7.50	(2.3)	29.6	(2.3)	0
85	77.2	21	0.862	(2.3)	7.50	(2.3)	29.6	(2.3)	0
85	71.9	16	0.862	(2.3)	7.50	(2.3)	29.6	(2.3)	0
50	5.2	16	0.861	(3.8)	7.60	(3.8)	31.3	(3.8)	0.5
36	5.4	19	0.861	(3.8)	7.60	(3.8)	31.3	(3.8)	0.5
34	5.5	80	0.861	(3.8)	7.60	(3.8)	31.3	(3.8)	0.5
100	40.0	10	0.861	(3.8)	7.60	(3.8)	31.3	(3.8)	0
99	62.2	47	0.861	(3.8)	7.60	(3.8)	31.3	(3.8)	0
59	9.9	55	0.861	(2.8)	7.70	(2.8)	31.3	(2.8)	0
97	71.1	35	0.861	(2.8)	7.70	(2.8)	31.3	(2.8)	0
100	7.7	65	0.861	(2.8)	7.70	(2.8)	31.3	(2.8)	0
24	6.1	89	0.861	(2.4)	7.70	(2.4)	31.5	(2.4)	0
100	66.9	43	0.861	(2.4)	7.70	(2.4)	31.5	(2.4)	0
17	7.3	52	0.861	(2.4)	7.70	(2.4)	31.35	(2.4)	0
100	50.6	55	0.861	(2.4)	7.70	(2.4)	31.35	(2.4)	0
24	6.0	84	0.861	(2.5)	7.70	(2.5)	31.35	(2.5)	0
19	5.3	71	0.861	(2.5)	7.70	(2.5)	31.35	(2.5)	0

TABLE 8

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
10/3	1	M	Phase II crude oil is much more viscous than Phase I crude oil. Small drops of water get trapped within the oil. The oil was literally swept up by the unit leaving a clean swath of open water behind it. This patch of open water remained for a substantial period of time with the oil showing no great tendency to close the gap. A throughput efficiency close to 100% should be expected.
10/3	2	L	The test results were very similar in that again the unit left a clear swath of open water cut in the oil surface. Again very little redistribution of the surrounding oil into the open area occurred, and, again, the clean area behind the unit would indicate a throughput efficiency close to 100%. A great deal of oil remained coating the vanes of the unit.
10/6	3	M	As was the case for Test 1, again the unit cut a clean swath out of the oil slick, but after this test, the remaining oil had a much greater tendency to fill-in the open water area that had been cleared.
10/6	5	L	Test 4 was dropped because while it was obvious that the Lockheed unit had recovered all of the oil in its path, very little had been obtained from the sump of the unit. Inspection indicated that the oil had been removed from the surface of the water, but was coating the vanes of the Lockheed unit. The oil had not entered into the disc area of the unit from which it could be recovered. Because of this, the test conditions of Test 4 were repeated for Test 5, and a procedure was established whereby the Lockheed unit would be primed prior to each test so that the unit would be saturated on all surfaces with oil at both

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			the start and end of a test run. The unit recovered all of the oil that it saw, for all practical purposes, again leaving a clean open water swath in the oil surface equal to the width of the unit.
10/7	7	M	The 24 tons of ice that were added to the basin tended to push all of the oil towards the far end of the basin. This oil was then redistributed to a nearly uniform thickness only after a great effort. The oil for the most part stayed between the ice pieces with very little oil coating the ice pieces themselves. The static ice processor test indicated that the processor acted essentially as planned, moving the large ice chunks out of the path of the device while the smaller ice pieces still tended to block up the front of the device. The presence of the smaller ice pieces likely hindered the ability of the oil to get to the belt of the unit since the very viscous crude oil does not flow very well between ice pieces. With the very viscous oil, the accumulation of ice pieces acted much like a plow pushing the oil away from the belt of the unit.
10/7	8	L	In processing the ice down and behind the unit, the unit appeared to be leaving a relatively clear span of water with cleaner pieces of ice. On the afterside of the unit however, globs of the heavy oil appeared to be thrown off the vanes of the unit. Some of this oil surfaced immediately behind the unit and other portions of it surfaced as far back as 20 feet behind the unit. This type of throughput inefficiency had not been observed in the Phase I program. This mode of throughput inefficiency would also indicate that the throughput efficiency might be improved by reducing the number of vanes on the unit such

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			that fewer vanes would be coated with the oil, and therefore fewer vanes would be throwing off oil astern of the unit.
10/8	9	M	The centerline of the freewheeling ice processor was mounted about 2 1/2 inches above the oil/air interface. The processor rotated only over about 1/4 the length of the run, remaining stationary and pushing the ice and oil ahead of it for the remainder of the run. Smaller ice pieces which were not pushed ahead or aside had a tendency to move around the side of the freewheeling ice processor and close in behind it, with the result that a buildup of small ice pieces occurred on the nose of the Marco unit, again tending to keep the oil away from the unit. This indicates that the region between any ice processor and the Marco belt should be screened to prevent the ice from reentering the area. The freewheeling processor concept appears valid, however, a combination of a higher centerline distance and a larger wheel diameter appears to be necessary.
10/8	10	L	With eight of the vanes of the Lockheed unit removed, it appeared that the amount of oil being slung off the vanes on the backside of the unit had been reduced as expected. However, an increase in the amount of oil passing through the unit was observed. This would indicate that the presence of the vanes does indeed tend to contain the collected oil within the drum of the unit, thereby increasing the time and opportunity for the oil to be deposited upon the discs of the unit from where it can be recovered. No significant damage to the discs with the 8 vanes removed was detected.

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
10/9	11	M	The active ice processor was mounted on the nose of the Marco unit such that the top of the drive shaft extended about 1 1/2 inches above the oil/air interface. The active ice processor appeared to process the ice very effectively as planned, however, it appeared to also have a tendency to process the oil along with the ice, driving both the ice and the very viscous oil down and under the Marco boom.
10/9	12	L	With 16 vanes removed from the unit,only 8 vanes remain on the drum. Some oil was still observed being thrown off the vanes of the unit, however, a much greater amount of oil was observed passing through the unit when the drum areas where the vanes had been removed surfaced. Because of this substantial amount of oil passing through with the vanes removed, the vanes were reinstalled for the remainder of the crude oil test program. The strapping used to hold down the vane tips at either end of the unit was not reinstalled for this test and no damage to the vanes was observed. The protection afforded the vane ends by the fairing appears to be adequate and the use of bands to eliminate the bending of the vane ends no longer seems necessary.
10/10	13	L	Again, a great deal of effort was required to redistribute the oil in a more uniform manner throughout the basin. Measurements indicated that the oil had a tendency to gather at the two ends of the basin as testing progressed. The drum speed is not as uniform as would be desirable. It appears that the unit is occasionally overloaded, possibly due to the very viscous oil and possibly due to interference with ice pieces. The unit seems to be somewhat underpowered with the Marco power supply. No increased tendency toward

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			damage was observed due to the higher speed of advance of 1 fps.
10/10	14	L	Again, the unit bogged down a bit at the start of the run, but then picked up to what appeared to be a normal speed of rotation. At this high forward speed of 1 1/2 fps, much of the ice and oil seemed to be pushed ahead of the unit as it progressed down the length of the basin. At this combination of drum and forward speed, the unit does not process the ice as fast as it approaches the ice.
10/13	16	M	The unmodified Marco device had a tendency to push a large mass of ice pieces ahead of it. These ice pieces appeared to push the oil away from the nose of the unit, thereby preventing it from being recovered by the belt. The pile-up of ice pieces appeared to be more severe in this unmodified condition than it was with the static ice processor in place.
10/15	18	M	The active processor was extended about 8 feet forward of the unit at the waterline, and the region between the processor and the boom was sectioned off with chain link fencing having a 2 inch grid spacing to prevent the re-entrance of ice pieces. The active processor processed the ice pieces very effectively, pushing them down after which they apparently floated back up to the surface alongside the chain link barrier. The path of the oil, however, could not be clearly seen. The oil that was trapped within the chain link barrier at the surface fed itself very slowly to the Marco unit. Much of this surface oil appeared to be trapped by the chain link fencing ahead of the unit. Some oil may have entered through the sides of the fencing due to forward motion. No oil was detected entering directly through

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			the active processor, nor was any oil detected rising to the surface from beneath the fenced area. The observation was made that it might be beneficial to reduce the belt speed such that the oil slick could be pulled towards the belt in a continuous layer rather than being snatched off in pieces. Another observation was that possibly if the barrier were widened as it extended towards the belt, the oil may sheer off of the mesh more easily. A change in the barrier screen was then made such that the width of the unit increased from the active processor to the belt.
10/15	19	L	Drum rotation appeared to be relatively uniform throughout the test. The oil coating on the vanes was thicker at the conclusion of the test then it was at the start of the test.
10/16	20	M	The barrier spacing at the active processor of 2 feet was widened at the belt to about 4 feet. Whether this widened processor helped the oil slick to shear off of the sides of the screen is questionable. The oil slick appeared to continue to move with the unit rather than being sheared off from the barrier.
10/16	21	M	Very little oil appeared to be recovered with the induction pump not operating. The induction pump does indeed appear to be necessary to obtain good oil recovery.
10/16	22	M	At this slower belt speed, the unit did appear to recover the oil in more of a continuous strip.
10/16	23	M	The speed of the active processor was increased in accordance with the higher forward speed of 1.5 fps. Even at this high speed the active ice processor worked very well, gathering the ice down and under in a very effective manner.

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			The action of the oil into the recovery area could not accurately be determined, but it appears to be entering primarily through the sides of the chain link barrier. Stress lines were visible in the surface of the oil showing how the oil had passed through the sides of the chain link mesh.
10/20	24	M	For the first time since the active processor has been relocated well forward of the boom, passage of oil through the active processor itself was clearly detected. A build-up of oil was observed just beyond the active processor within the screened-in area. However, as much, or more, oil seemed to enter through the sides of the screen as through the active processor directly ahead of the unit. The unit appeared to leave a very clean swath behind it which gradually was filled in by the oil slowly redistributing itself with the ice.
10/20	25	L	With this greater oil thickness,the build-up of oil on the vanes of the unit, and the subsequent slinging off of the oil from the vanes on the downstream side of the unit, appeared to be greater than was the case in the thinner slick. It is conceivable, although not proven, that the very heavy build-up of oil on the vanes may have restricted the entrance of the oil through the vanes into the disc area.
10/21	26	OM	At the start of the test, the Oil Mop recovered a substantial amount of crude oil at what appeared to be a very high oil recovery efficiency, that is, very little water was collected with the recovered oil. The rope did have a tendency to clean a swath in the oil layer, however, it continued to gather oil to itself over a significantly longer period of time than had been expected. The

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			squeeze rollers seemed to have no difficulty removing this very viscous oil from the rope.
10/21	27	OM	The idler end of the rope was moved laterally 1.4 feet at 2 minute intervals. The rope seemed to glide over the ice pieces with no difficulty. The unit appears to have some advantages in this type of application.
10/21	28	OM	This test was run for a period of 1 hour without moving the Oil Mop rope, with samples taken at 15 minute intervals. The oil recovery rate at the start of the run appeared to be quite high. Again the rope has a tendency to clean a swath in the very viscous oil, however, there is also some tendency for it to continue to gather some oil to itself. The rope gradually has a tendency to shift from riding over the top of the ice pieces to riding in the spaces between the ice pieces where the bulk of the oil lies. The highest rope speed is still quite slow, measured at about 0.15 fps.
10/23	29	OSI	The OSI unit gathered a mass of broken ice pieces ahead of it as it moved through the water, and this mass of ice appeared to push additional ice and the oil surrounding the ice pieces away from the unit. Very little oil was seen getting to the mouth of the unit. No problem was experienced with the flexible fabric of the unit in its interaction with broken ice.
10/23	30	JBF	The debris screen was removed from the front of the JBF unit in the hope that the moving belt would have some tendency to process the ice down and under the unit. Some complications were experienced at the start of the

TABLE 8 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING STANDARD CRUDE OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			run due to freeze-up of the pneumatic control lines. In actuality, the moving belt did not have a tendency to process the ice. The ice pieces primarily stayed in front of the unit, and this build up of ice pieces appeared to push the oil away from the inlet of the unit.
10/23	31	JBF	This test of the installed propulsion system on the JBF unit showed that the system was inadequately powered to move the unit through a tightly packed ice field of this nature. The only movement that could be imparted to the device through the use of the two propulsion screws was a side-to-side swinging motion. No forward motion could be achieved at all.
10/30	38	L	Difficulty was experienced in maintaining the low drum speed without stalling the unit. Also, at this low drum speed there is a much greater tendency for ice to be pushed, or rafted, ahead of the unit. The drum is not rotating fast enough to process the ice down and behind the unit as fast as it approaches the ice.

TABLE 9

SUMMARY OF NOTATIONS MADE DURING NO. 2 FUEL OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
11/7	45	M	A substantial amount of froth is left behind the unit, apparently due to emulsification of the oil caused by the induction pump.
11/7	46	L	A fairly clean swath is left immediately behind the Lockheed unit similar to the swath left in the open water crude oil test, however, the swath fills in with oil from the side rather rapidly. Also clearly visible in the test were pulsed discharges from the drum on the backside of the unit corresponding to the surfacing of each vane. As each vane approached the surface on the backside of the drum, a volume of oil was released.
11/10	47	L	Observations were similar to the preceeding test with the clear swath filling in behind the unit less rapidly because of the lesser oil thickness, and with a lesser amount of oil being discharged as the vanes surface on the backside of the unit, also apparently due to the lesser oil thickness.
11/10	48	M	A froth due to the churning of the induction pump was again observed.
11/11	49	M	A fair number of small ice pieces passed through the 2 inch square mesh of the chain link fencing and gathered at the nose of the boom, however, the light oil seemed to find its way through the broken ice pieces with no difficulty. Oil entered into the screened-in area very easily through the sides.
11/11	50	L	The Lockheed unit processed the ice very effectively and left a relatively clean swath immediately behind the unit with periodic discharges of oil on the backside as the vanes surfaced.

TABLE 9 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING NO. 2 FUEL OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
11/12	51	M	Oil appeared to enter primarily through the sides of the screen rather than directly head-on through the active ice processor. Some frothing of the oil ahead of the boom was observed due to the action of the active processor which was set at a higher speed corresponding to the higher forward speed of 1 fps.
11/12	52	M	With the speed of the active processor set still higher to correspond to the higher forward speed of 1.5 fps, a substantial amount of churning of the oil, water, and air resulted in a substantial amount of froth being recovered by the unit.
11/12	53	L	At this higher forward speed of 1 fps, there was some rafting of the ice ahead of the unit along with some ice processing. It would appear that a slightly higher drum speed would be required to process the ice as fast as the unit approaches it at this value of forward speed.
11/12	54	L	At this still higher forward speed of 1.5 fps, additional rafting of the ice ahead of the unit was observed.
11/13	55	M	This low value of belt speed of 1 fps appears to be too slow for the forward speed of the unit. The emulsification and churning of oil by the active processor is substantially less at the standard forward speed of 0.5 fps.
11/13	56	M	Very few ice pieces penetrated the screen during this test.

TABLE 9 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING NO. 2 FUEL OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
11/13	56A	M	The previous test was rerun because the belt speed was incorrectly set.
11/13	57	L	At this low speed of drum rotation the unit was not able to process the ice as it was approached, therefore a substantial amount of ice rafting occurred.
11/13	58	L	At this high value of target drum speed of 13 rpm, the Lockheed unit easily processed all of the ice as it was approached by the unit. The unit actually had a tendency to draw the ice to itself, with ice motion observed several feet ahead of the unit. The area immediately behind the unit appeared to have a greater amount of oil mixed with the water than was the case for previous tests, indicating perhaps that at this high value of drum speed there is a greater tendency for more oil to be entrapped with the water and driven around the drum, rather than getting into the center of the drum from where it can be recovered.
11/14	59	M	At this greater oil thickness no emulsification of oil due to the action of the active ice processor was observed. There was an accumulation of very small ice pieces within the screened area.
11/14	60	L	At this greater oil thickness the spillage out through the vanes as they surfaced on the backside of the unit appeared to be somewhat greater than in the thin slick case. Aside from this, the unit appeared to leave a relatively clean swath of water behind it.
11/14	61	OM	The performance of the Oil Mop in fuel oil was considerably reduced from that observed in crude oil. Relatively little oil seems to be

TABLE 9 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING NO. 2 FUEL OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
			gathered within the rope, and a substantial amount of the oil dripped back off of the rope as it was lifted the 1 to 1.5 feet from the water surface to the squeeze rollers. The rope did have a tendency to move the ice pieces around a bit during the first couple of minutes of operation, after which the ice pieces remained relatively stationary as the rope continued to travel in the same path between ice pieces. This oil just appears to be too light to be effectively recovered with the Oil Mop unit.
11/17	62	M	In the light fuel oil, the close-coupled active processor appeared to work very effectively. A slight amount of emulsification of the oil due to the action of the active processor was observed.
11/17	63	L	With 8 vanes removed from the Lockheed unit, the spillage from the area where the vanes had been removed on the backside of the unit appeared to be increased over the case with all vanes present.
11/18	64	M	The freewheeling processor rotated more readily than it did in the crude oil portion of the test program, however, it was still clear that a larger diameter wheel and a higher mounting of the wheel above the oil/air interface would be desirable. The wheel rotated for about two-thirds of the length of the run and then jammed and remained stationary for the remainder of the run. Oil seemed to find its way through the ice pieces and the processor to the Marco boom even after the freewheeling processor jammed. The light oil penetrates a mass of broken ice much more readily than does the crude oil used in the earlier part of the program.

TABLE 9 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING NO. 2 FUEL OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
11/18	65	L	With a total of 16 vanes removed from the unit leaving only 8 in place, oil spillage through the Lockheed unit on the backside appeared to be increased. Some damage of the fingers of the discs where the vanes had been removed was observed, but this damage was all of a minor nature.
11/19	66	M	The static ice processor on the Marco unit effectively cleared the larger ice pieces from blocking the entrance to the belt, however, small ice pieces did pass over the processor and gathered at the belt. These small ice pieces did not appear to significantly restrict the flow of the light fuel oil to the unit however.
11/19	67	M	The unmodified Marco unit definitely has a greater tendency to have a build-up of large ice pieces occur at the nose of the unit than was the case with the static ice processor.
11/20	68	L	It took about 30 minutes for the leading edge of the oil to move up to an equilibrium distance of about 1 inch from the drum, occasionally lapping up to touch the backside of the drum. After about 50 minutes the depth of oil at the barrier seemed to achieve an equilibrium value of about 2 1/8 inches. At this time the oil would lap against the backside of the drum on a fairly regular basis.
11/20	69	L	In this greater oil slick thickness, the leading edge of the oil moved up to touch the drum in about 3 minutes, and the oil depth in the barrier reached its equilibrium value in about 10 minutes.
11/20	69A	L	At this greater oil thickness and higher drum speed the barrier region filled up very rapidly with oil.

TABLE 9 (CONT'D)

SUMMARY OF NOTATIONS MADE DURING NO. 2 FUEL OIL RECOVERY TESTS

Date	Test No.	Device	Remarks
11/21	70 to 80	L	In the barrier tests incorporating forward motion, efforts were made to observe whether or not any oil escaped from beneath the barrier. Because of the redistribution of oil on the surface of the water observations were very difficult to make, however, during the period when observations could be made with confidence, no release of oil below the barrier was observed.

TABLE 10

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED IN OPEN WATER

Device	Type Oil	Oil Thickness cm	Oil Recovery Rate gpm	Unit Oil Recovery Rate gpm/ft	Oil Recovery Efficiency %	Throughput Efficiency %	Test No.	Comments
Lockheed	C	0.73	24.6	3.45	62	63	5	
Lockheed	C	1.27	15.1	2.12	71	23	2	Inadequate priming.
Lockheed	#2	0.73	19.7	2.76	98	48	47	
Lockheed	#2	1.27	37.4	5.25	98	54	46	
Marco	C	0.73	7.0	6.46	46	118	3	
Marco	C	1.27	10.1	9.32	32	99	1	
Marco	#2	0.73	6.7	6.18	31	111	48	
Marco	#2	1.27	6.0	5.54	26	57	45	

As previously indicated in the summary of test commentary presented in Table 8, both units cleared a clean swath of heavy crude oil from the surface of the basin in the open water tests. The appearance of the surface of the model basin after the devices had passed resembled what would be left if someone had cut a swath in a carpet and rolled it up. Figure 20 is a photograph of the clean swath left on the surface following passage of the Lockheed device in an open water test with crude oil. Clearly, nearly all of the oil had been removed from the water surface across the full width of the disc drum unit. The data obtained from the Lockheed tests in crude however, as summarized in Table 10, showed throughput efficiencies for these two tests of only 23 and 63 percent. After analyzing the data from Test 2, it was realized that a substantial amount of the oil remained on the disc drum unit as a very thick coating of oil on the vanes. This oil had been removed from the surface of the water but had not penetrated through the vanes of the unit to the discs from which it could be recovered. The coating on the vanes was not so severe so as to preclude the entrance of oil between the vanes, however, the amount was substantial. For this reason, the data of Test 2 is considered to be of questionable value and the procedure for further testing of the Lockheed unit in crude oil was modified as a result of this inconsistency between observations and measured data. For subsequent Lockheed tests the unit was primed over a distance of 15 to 20 feet prior to the start of data collection, with the objective being to saturate the unit to an equilibrium level prior to the start of data collection in the same manner that the unit would be saturated by the end of a test run. The procedure used prior to this was the same procedure that was used in Phase I testing where the unit was rotated in air prior to each test and similarly raised free from the oil/water surface and rotated again in air at the conclusion of the test, such that the discs of the unit were wiped clean at the start and end of a test. The new priming procedure was used for Test 5, the second test of the Lockheed unit in crude oil and open water conditions. Again, test observations indicated that the unit had removed everything in its path over the length of the run, however the calculated throughput efficiency is 63%, indicating that even with the new priming procedure in this case, it is likely there was still a greater build-up of oil on the vanes of the unit at the completion of the test then there was at the start of the test. Carrying this line of thought to its limit, the question arises as to whether or not the Lockheed unit, when operated in great thicknesses of extremely viscous oil such as the crude oil used in the Phase II program, would build-up a great enough thickness of oil on the vanes of the unit such that oil would no longer penetrate through the openings between the vanes to the discs from which the oil is recovered. Unfortunately, the limitation of the model basin precluded any further evaluation of this possibility with the crude oil tested. Certainly, in the extreme case of sufficiently viscous oil, one can envision such an occurrance.

FIGURE 20. PHOTOGRAPH OF THE CLEAR WATER SWATH LEFT IN THE 1.27 CM THICK SLICK OF CRUDE OIL IN OPEN WATER AFTER PASSAGE OF THE LOCKHEED OIL RECOVERY DEVICE.

In comparing the two open water tests of the Lockheed unit operating in No. 2 fuel oil, the ratio of the oil recovery rates is nearly equivalent to the ratio of the oil thicknesses. This would indicate that the unit was being fed less oil than it was capable of recovering at a thin slick thickness, and most likely is still underfed even at the greater slick thickness of 1.27 cm. The oil recovery efficiency of the Lockheed unit operating in No. 2 fuel oil is outstanding. The oil recovery efficiency of the unit operating in crude oil is somewhat less. For operation in No. 2 fuel oil, the throughput efficiency dropped below that obtained for the single crude oil test which provides the more valid comparison, Test 5.

In reviewing the oil recovery data obtained with the Marco unit in open water, the obvious eye catchers are the two throughput efficiencies recorded as being greater than 100%. Throughput efficiencies greater than 100% are indeed possible for the Marco unit since the unit draws oil to itself through the action of the induction pump. In all likelihood, the effective swath width of the unit is somewhat greater than the actual belt width of 13.0 inches, resulting in theoretical throughput efficiencies greater than 100%. The operation of the Marco unit in crude oil was very similar to that of the Lockheed unit, in that the Marco unit also cleared a swath of oil in a manner resembling rolling up a strip of carpet. Figure 21 is a photograph of the swath cleared in the 1.27 cm thickness of crude oil by the Marco unit. The oil was so viscous that the swath closed in an extremely slow manner, the motion being so slow as to be imperceptable to the eye. After a period of approximately 15 minutes, the swath width had narrowed in some areas by possibly 1 to 2 inches. For the Marco tests run in curde oil, a comparison of the the oil recovery rate obtained at the two slick thicknesses indicates that the unit was capable of recovering more oil than it saw at the lesser slick thickness. It is important to note however, that in the case of very heavy oil, the Marco unit recovered oil not only by absorbing oil within the pores of the belt, but also due to a very heavy layering effect on the surface of the belt. In this case the belt acts much like a conveyor rather than a Filterbelt.

For the two runs with the Marco unit conducted in No. 2 fuel oil, the similar oil recovery rate of 6 to 7 gpm indicates that the belt might be saturated at even the lesser slick thickness for this lighter oil since significantly increasing the oil thickness did not result in an increase in the oil recovery rate.

In comparing the open water test results of the Lockheed unit with those of the Marco unit, the oil recovery rates achieved by the Lockheed unit are seen to be in the range of 15 to 37 gpm, while those obtained by the Marco unit range from 6 to 10 gpm. On the basis of the unit width of the device however, the unit oil recovery rates obtained from the Lockheed unit ranged from 2 to 5 gpm per foot, while

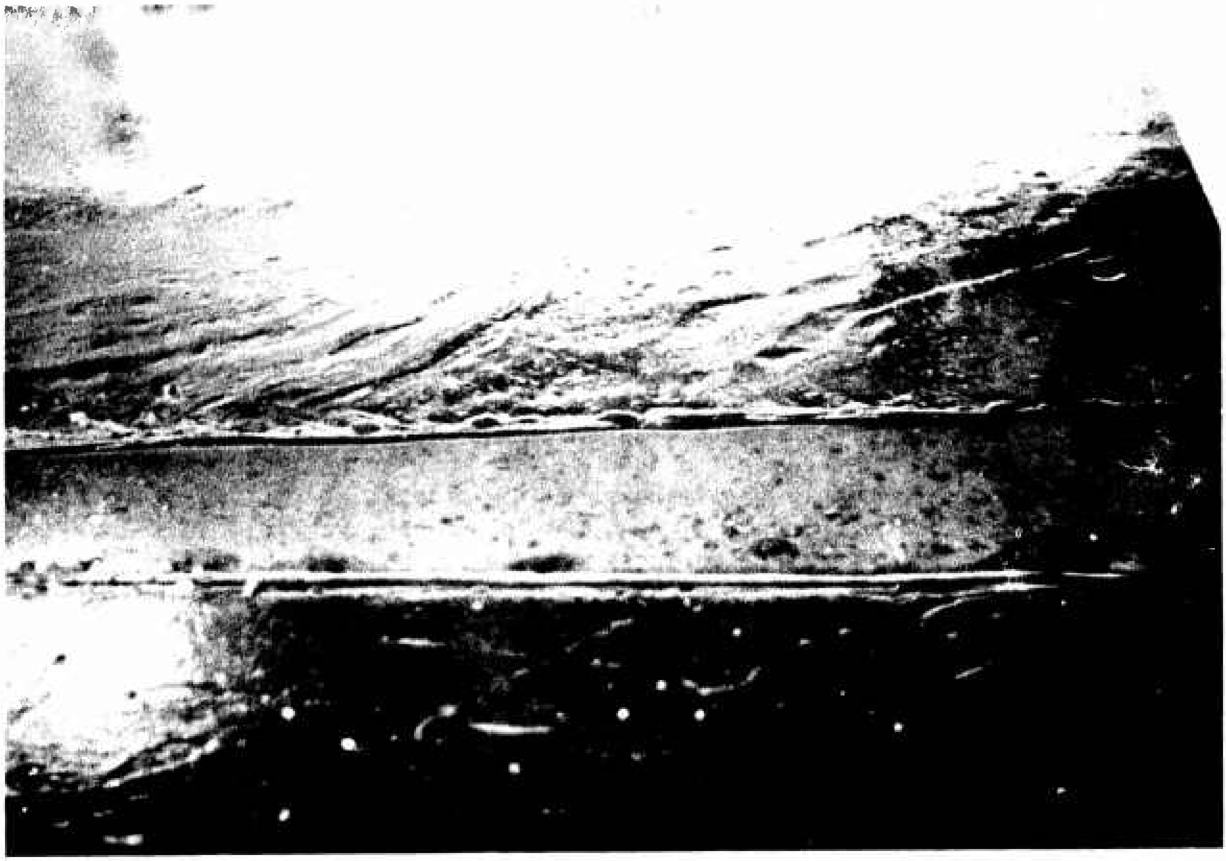


FIGURE 21. PHOTOGRAPH OF THE CLEAR WATER SWATH LEFT IN THE 1.27 CM THICK SLICK OF CRUDE OIL IN OPEN WATER AFTER PASSAGE OF THE MARCO OIL RECOVERY DEVICE.

the Marco unit recovery ranged from 5 to 9 gpm per foot of device width. In general, the Lockheed unit has a higher oil recovery efficiency than does the Marco unit. In particular, in the light No. 2 fuel oil the Lockheed oil recovery efficiencies of 98% are outstanding. As for the throughput efficiency, the range of 48-63% obtained with the Lockheed unit compares to the range of 57-118% obtained with the Marco unit.

Analysis of the Lockheed Unit's Performance in Ice

The results of the standard oil recovery tests conducted with the Lockheed unit in ice-infested waters with both crude and No. 2 fuel oil are summarized in Tables 11 and 12 respectively. The data summarized in Tables 11 and 12 have been extracted from the tabulation of all test data in Tables 4 through 7. Summarized in the two tables are the number of vanes in place for that particular test, the speed of advance of the unit, the speed of drum rotation, the oil recovery rate, the unit oil recovery rate, the oil recovery efficiency, the throughput efficiency, the nominal oil thickness, and the test number. The data are grouped such that the first three rows provide the performance variation as a function of the number of vanes, the next two rows along with the first row provide the performance variation as a function of speed of advance, and the next two rows along with the first row provide the performance variation as a function of the speed of drum rotation. The last row of data in each table summarizes the oil recovery data for the 1/2 inch (1.27 cm) nominal slick thickness case which was included in the program for purposes of comparison to Phase I results.

The oil recovery data summarized in Tables 11 and 12 are plotted in Figures 22, 24 and 25. Figure 22 is a plot of the performance of the Lockheed unit in ice as a function of the number of vanes in place on the drum of the unit. The test results obtained for operation in crude oil are shown by the solid data points and solid lines, while the data obtained for tests conducted in No. 2 fuel oil are shown by the open data points and the dotted lines. The curves of Figure 22 show the generally lower level of performance as measured by oil recovery rate, oil recovery efficiency, and throughput efficiency, obtained for operation of the unit in crude oil in comparison with operation in No. 2 fuel oil. For operation in crude oil, the oil recovery rate is seen to be best for the case with all 24 vanes installed while the performance curve of oil recovery rate in No. 2 fuel oil shows the performance to be improved with a lesser number of vanes installed, with the poorest performance in No. 2 fuel oil achieved with all 24 vanes installed. In addition, the fuel oil test results show both the oil recovery efficiency and the throughput efficiency to be improved with a fewer number of vanes

TABLE 11

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED WITH THE LOCKHEED DEVICE IN CRUDE OIL AND ICE-INFESTED WATERS

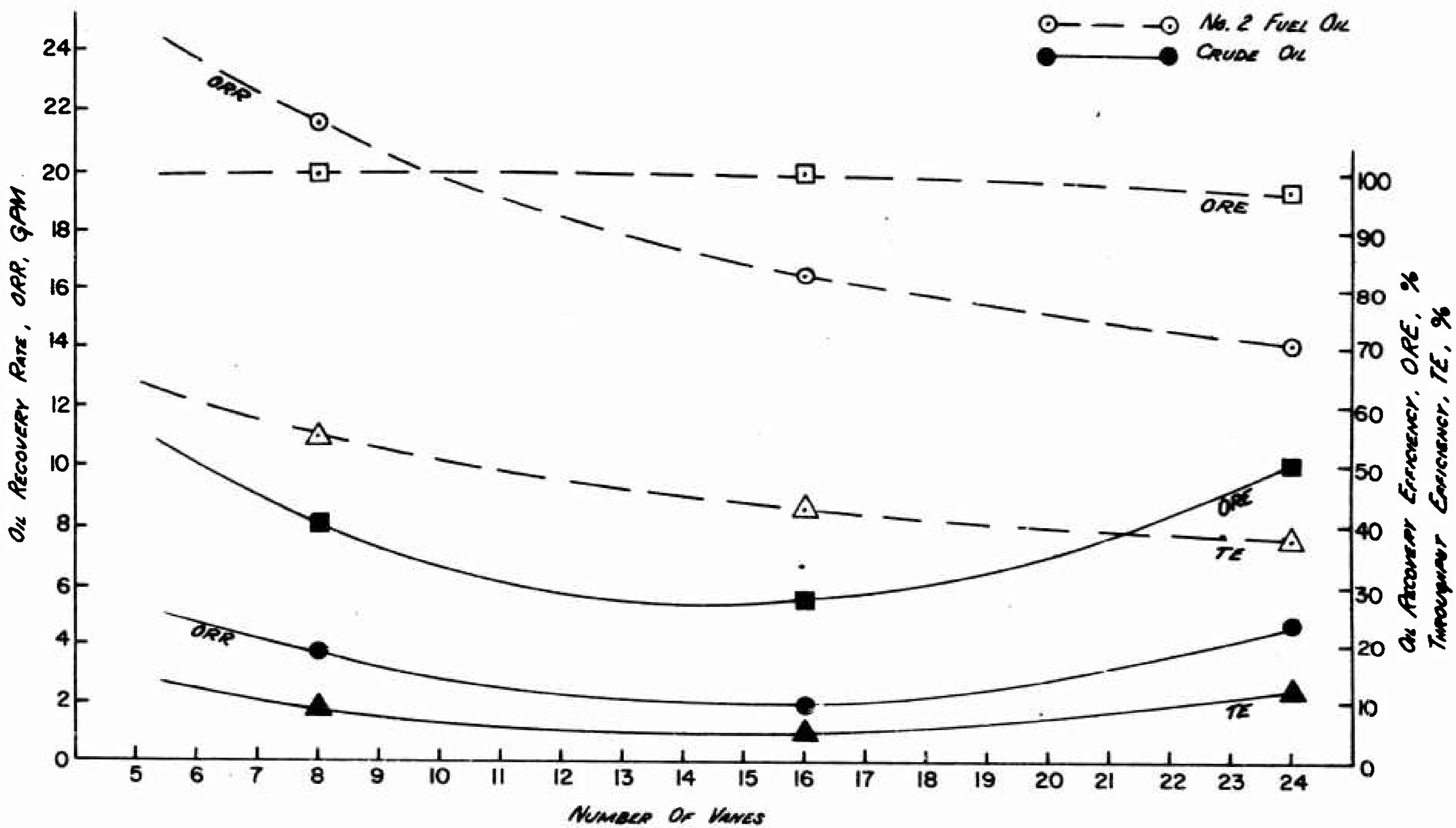
Number of Vanes	Speed of Advance fps	Speed of Drum rpm	Oil Recovery Rate gpm	Unit Oil Recovery Rate gpm/ft	Oil Recovery Efficiency %	Throughput Efficiency %	Oil Thickness cm	Test No.
24	0.50	6.25	4.7	0.66	50	12	0.73	8
16	0.51	6.5	1.9	0.27	28	5	0.73	10
8	0.51	6.9	3.7	0.52	41	9	0.73	12
24	1.00	7.3	4.6	0.65	52	6	0.73	13
24	1.43	7.2	3.6	0.51	30	3	0.73	14
24	0.65	2.7	5.2	0.73	82	11	0.73	38
24	0.50	11.5	6.8	0.95	29	18	0.73	19
24	0.49	6.3	5.8	0.81	51	9	1.27	25

TABLE 12

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED WITH THE LOCKHEED DEVICE IN NO. 2 FUEL OIL AND ICE-INFESTED WATERS

Number Of Vanes	Speed of Advance fps	Speed of Drum rpm	Oil Recovery Rate gpm	Unit Oil Recovery Rate gpm/ft	Oil Recovery Efficiency %	Throughput Efficiency %	Oil Thickness cm	Test No.
24	0.48	7.4	14.1	1.98	97	38	0.73	50
16	0.51	7.1	16.5	2.32	100	43	0.73	63
8	0.52	8.7	21.6	3.03	100	55	0.73	65
24	0.95	8.1	15.0	2.11	85	21	0.73	53
24	1.06	8.7	13.3	1.87	85	16	0.73	54
24	0.51	2.8	4.1	0.58	100	10	0.73	57
24	0.51	11.0	18.3	2.57	99	47	0.73	58
24	0.52	7.5	24.4	3.42	97	35	1.27	60

FIGURE 22. PERFORMANCE OF THE LOCKHEED UNIT IN ICE AS A FUNCTION OF THE NUMBER OF VANES



installed. In comparison, the crude oil test results show the highest oil recovery efficiency and throughput efficiency obtained with all 24 vanes installed. Observations made in the course of this test program, revealed three possible ways in which the number of vanes could affect the oil recovery performance of the Lockheed unit. The first phenomenon observed is a tendency for the unit to drive some of the oil downward along with the ice into the water column as it advances, thereby passing over this oil without recovering it. Conceivably, as the number of vanes are reduced, performance losses due to this phenomenon should also be reduced, hence the performance should improve as the number of vanes are reduced. A second phenomenon observed during the course of this program was the oil coating and subsequent release of oil from the vanes of the unit. This oil never had the opportunity to enter the drum portion of the unit from where it could be recovered. This phenomenon was particularly observed during heavy crude oil tests. Again, as the number of vanes are reduced, the losses due to this phenomenon should also be reduced, therefore, as the number of vanes are reduced the performance of the unit should improve. Finally, the third phenomenon observed during the program was the spillage of oil through the back-side of the unit as the individual vanes surfaced during drum rotation as shown in Figure 23. Since there is singular vane overlap in the Lockheed unit, that is, the removal of a single vane eliminates all vane overlap at that particular location, and in fact, results in a significant space between vanes, the effect of vane removal on oil recovery performance would be expected to be detrimental. As a result, performance should be reduced as vanes are removed, based on the assumption that conditions are such as to cause an oil build-up on the water surface within the disc drum unit itself. In the case of No. 2 fuel oil, observations indicated that coating of the vanes with oil and subsequent throw off from the vanes on the downstream side of the unit was insignificant. In addition, the very rapid separation of the light oil from the water could indicate that the effect of driving oil down into the water column might be less for the light fuel oil than would be the case for the heavier crude oil. In the case of the lighter fuel oil then, it would be expected that the major effect of removing vanes would be to allow a greater escape of oil through the unit on the downstream side. The data however, contradicts this line of thought, showing the oil recovery rate, the oil recovery efficiency, and the throughput efficiency all to improve as the number of vanes are reduced for operation in No. 2 fuel oil. Based upon this analysis then, it would appear that the water column entrainment problem is the major factor reducing the oil recovery performance of the unit in No. 2 fuel oil. Further testing and evaluation could reveal other oil escape paths which were not observed in this test program.

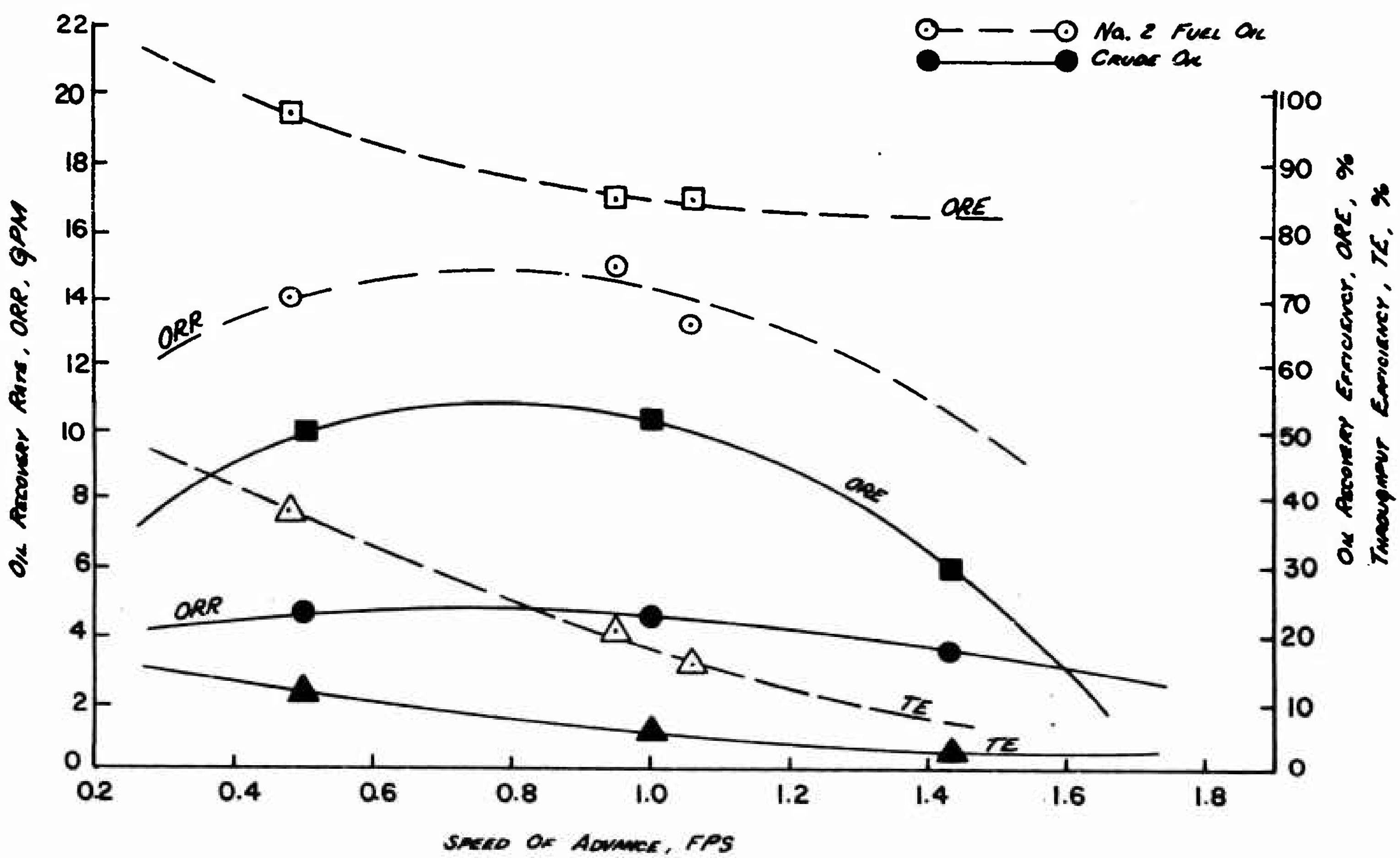
Reviewing the performance curves obtained from the crude oil tests in Figure 22, the curves indicate that a trade off may occur

FIGURE 23. PHOTOGRAPH OF THE SEQUENTIAL OIL SPILLAGE THROUGH THE BACK SIDE OF THE LOCKHEED UNIT TAKEN DURING A STATIONARY TEST IN OPEN WATER WITH THE BARRIER IN PLACE.

between the improvement in performance due to vane removal through the vane coating and throw-off effect in conjunction with the water column entrainment effect, and the expected reduction in performance due to reducing the number of vanes, through the effect of oil passing directly through the unit without being recovered. The crude oil curves however, also indicate that a further reduction of the number of vanes below the minimum number used in this program could improve oil recovery performance beyond the value obtained with all 24 vanes in place. This fact, plus the clear indication of improved performance with reduced vanes in light oil, might warrant that consideration be given to reducing the number of vanes installed on the Lockheed unit. In considering this action however, the contribution that the vanes make in effectively processing the ice must not be overlooked. For example, in the extreme case of removing all vanes and providing structural integrity to the discs through some other means such as internal tie rods, the ability of the unit to process ice with a perfectly smooth outer surface would likely be substantially reduced.

Figure 24 shows the variation in performance of the Lockheed unit in ice infested waters obtained during this test program as a function of the speed of advance of the unit. Unfortunately, an incorrect speed control setting in the high speed diesel oil test resulted in data having a narrower spread than was intended. However, in general the test results support an optimum speed of advance based on oil recovery rate in the neighborhood of 0.8 fps. Both throughput efficiency curves indicate that under these conditions the oil recovery device cannot recover anywhere near all of the oil that is available to it. The reason for this might be the loss of potentially recoverable oil due to the mechanisms described in the preceeding paragraph, or additionally due to the rafting of ice ahead of the unit which would tend to keep the oil theoretically available from actually presenting itself to the unit. The fact that the oil recovery rate tends to fall off at lower speeds of advance even though the throughput efficiency is still relatively low is somewhat puzzeling. One would expect that in the low speed range, the oil recovery rate would remain relatively constant down to the point at which the throughput efficiency approached 100%. Further speed reduction beyond that point would then result in a reduction of oil recovery rate since the unit is then recovering all that is available to be recovered over a longer period of time. The down turn in oil recovery rate at the lower speed range may not be an indicator of true performance, rather it may be a result of the very limited test data available. Since the opportunity was not available to accurately evaluate the repeatability of the test data, it is judged that based on the expected accuracy of the results, curves of oil recovery rate approaching a horizontal line at the lower speed of advance range would be equally as justifiable as the curves drawn based upon the three data points given for

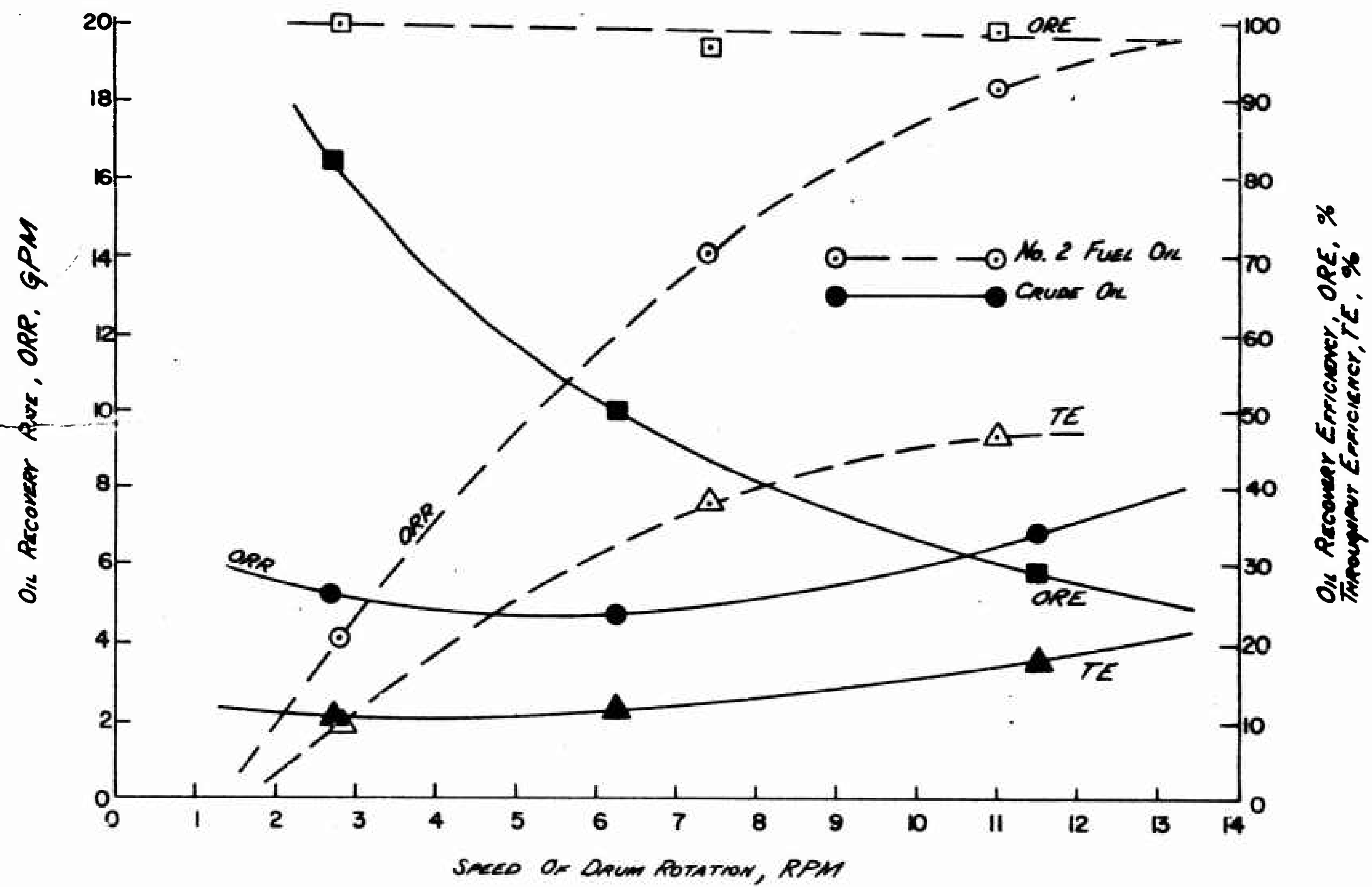
Figure 24. Performance Of The Lockheed Unit In Ice As A Function Of Speed Of Advance



each type of oil. Considering the curves of oil recovery efficiency, the results obtained for both types of oil show a fall off in oil recovery efficiency as the speed of advance increases, although the curves have reverse curvature. A fall off in oil recovery efficiency as the forward speed increases is not unreasonable since at the greater speed of advance the greater turbulance could result in a greater amount of mixing of the oil in the water in the case of the light No. 2 fuel oil, and could result in greater entrapment of water in the oil in the case of the heavier crude oil.

The variation of the oil recovery performance of the Lockheed unit in ice infested waters is presented in Figure 25 as a function of the speed of drum rotation. For the case of the light No. 2 fuel oil, the curves clearly show an increase in both oil recovery rate and throughput efficiency with an increase in the speed of drum rotation, at a very slight penalty in oil recovery efficiency. These results are generally as expected since the oil recovery rate would be expected to increase as the speed of drum rotation increases up to the point at which the throughput efficiency reaches its maximum value. The reducing slope of this curve as the speed of drum rotation increases could conceivably be due to the increased amount of entrainment of oil in the water column as the speed of drum rotation increases. This phenomenon could also explain the leveling off, and possible reversal, of the throughput efficiency with further increase in the speed of drum rotation. The slight fall-off in oil recovery efficiency as the speed of drum rotation increases is not unexpected since, as the speed of drum rotation increases, less time is allowed for the water to drain from the oil as the discs rotate toward the wipers. The performance curves obtained from the crude oil tests seem to vary considerably from those obtained from the No. 2 fuel oil tests. The oil recovery efficiency drops off as the speed of drum rotation increases in crude oil as it did in the lighter fuel oil, however the fall-off in the crude oil case is quite severe. This could be caused by the greater mixing of the crude oil and water at the higher speed of drum rotation and the relative difficulty of water separation after being entrapped within the very viscous crude oil. The curve of oil recovery rate for the crude oil case is seen to have a minimum point at about 5.5 rpm, with the oil recovery rate increasing at both lower and higher drum speeds. The increase in the oil recovery rate on the increasing drum rotation side of the curve is likely due to the ability of the unit to get at more oil at the higher speed of rotation as indicated by the corresponding improvement in the throughput efficiency. On the low speed side of the minimum point of the oil recovery rate curve, the increase, if real, that is if not within the scatter of the experimental results, could conceivably be due to a reduction in the amount of oil lost through entrainment in the water column or

FIGURE 25. PERFORMANCE OF THE LOCKHEED UNIT IN ICE AS A FUNCTION OF SPEED OF DRUM ROTATION



through throw-off from the vanes on the downstream side of the unit.

In summary then, the performance curves of Figures 22, 24, and 25 indicate the following:

1. The oil recovery performance of the Lockheed unit is highly dependent upon the type of oil being recovered, not only in the extent of performance change due to a change in operating conditions, but more importantly, in the direction of the performance change for a given change in operating conditions. The achievement of optimum oil recovery performance in the field will therefore be highly dependent upon operator skill.

2. The results of this test program indicate that oil recovery performance as measured by oil recovery rate, oil recovery efficiency, and throughput efficiency could be improved through the reduction of the number of vanes installed on the Lockheed unit in the case of the lighter oils. Improvements might also be achieved in the case of heavier oils if the number of vanes could be reduced to a sufficient extent.

3. These tests indicate that the oil recovery rate can be optimized at a forward speed of advance of about 0.8 fps for the conditions tested. Oil recovery efficiency and throughput efficiency fall-off at higher values of forward speed.

4. In light oils, the oil recovery rate achieved by the Lockheed unit can be increased substantially as the speed of drum rotation is increased, at least up to about 12 rpm. In heavy oils, the increase in oil recovery rate with increasing speed of drum rotation is not as dramatic, but perhaps could be increased further through even greater drum speeds.

At the conclusion of the planned test program, some additional tests were run with a barrier installed behind the Lockheed unit. This barrier, described in an earlier section of this report, was intended to contain the bulk of the oil which was evading the Lockheed oil spill recovery unit. It was conceivable that the barrier would contain all of the oil that was escaping from the vanes on the downstream side of the unit, most of the oil that was being entrained in the water column as the drum rotated downward, and all the oil that was being thrown off of the vanes on the downstream s de of the unit. These additional tests were conducted in the light No. 2 fuel oil since that was the oil that was in the basin at the conclusion of the planned test program. To further simplify the testing procedure and in order to obtain as much oil recovery data as was possible in the time period remaining, these tests were conducted in open water

only with the ice rafted to the far end of the model basin. In addition, only oil recovery data was recorded, as opposed to the standard set of pre-test and post-test data. For this reason, the results of this test were not presented in Table 7, the summary of post-test data for tests in No. 2 fuel oil. The objectives of these tests were to evaluate the containment capability of such a barrier and to determine whether or not secondary recovery on the backside of the Lockheed drum from the barrier would occur. In order to meet these objectives, two types of tests were conducted. The first tests were conducted with the Lockheed oil spill recovery device in a stationary mode, that is, with no forward motion. The objective of the stationary tests was to observe the build-up of oil within the barrier region and to determine if secondary recovery on the backside of the Lockheed drum occurred. Following the stationary tests, moving tests were conducted to determine the effect forward velocity would have on the performance of the throughput barrier and the ability of the Lockheed drum to recover oil from the throughput barrier region on the backside of the drum.

Two tests were conducted in a stationary mode. The set-up for these tests consisted of locating the Lockheed oil spill recovery device in a fixed position in open water after rafting the ice to one end of the model basin. The barrier was clamped into place and the region between the drum and the barrier was evacuated of all oil. The drum was then rotated with corresponding oil recovery. The recovered oil was recirculated to the front of the oil recovery device, with the output sampled at 3 minute intervals to determine the oil recovery rate. At the same 3 minute intervals, the distance at the waterline between the backside of the drum and the head wave of the oil was measured, along with the depth of oil just inside the barrier. Table 13 is a summary of the first stationary barrier test of the Lockheed unit, Test 68, with the drum rotating at 4 rpm in a slick thickness of 1.27 cm of No. 2 fuel oil. The data presented includes the elapsed time from the start of the test, the distance between the backside of the drum and the oil head wave measured at the waterline, the depth of the oil just inside the barrier, and the oil recovery rate as determined by sampling. At this low slick thickness and low drum speed, it took a significant amount of time for the oil head wave to build-up to where it approached the backside of the drum. After about 25 to 30 minutes, the oil head wave would periodically lap against the backside of the drum. The recorded distance from the backside of the drum to the oil head wave is tabulated as a stationary one inch after the first 27 minutes. This one inch measurement, however, includes a periodic lapping of the backside of the drum by the oil contained within the barrier. The depth of the oil at the barrier is seen to build-up fairly rapidly to an

TABLE 13

SUMMARY OF DATA FOR STATIONARY BARRIER TEST OF THE LOCKHEED UNIT OPERATING AT 4 RPM IN OPEN WATER AND 1.27 cm OF NO. 2 FUEL OIL (TEST NO. 68)

Elapsed Time min.	Distance to Oil Headwave inches	Depth of Oil at Barrier inches	Oil Recovery Rate gpm
0	30	0	0
3	23	0.625	10.6
6	16	0.75	9.1
9	15	0.875	9.1
12	10.5	1.125	8.4
15	7	1.375	8.4
18	5	1.375	9.5
21	2	1.5	8.7
24	2	1.5	8.2
27	1	1.625	7.0
30	1	1.75	7.6
33	1	1.875	8.0
36	1	1.875	8.0
39	1	1.875	8.0
42	1	2.0	7.6
45	1	2.0	7.6
48	1	2.06	6.8
51	1	2.125	7.0
54	1	2.125	7.2
57	1	2.125	7.6
60	1	2.125	8.2
63	1	2.125	8.7
66	1	2.125	9.1
69	1	2.125	8.2
119	1	2.25	8.9
132	1	2.125	9.5

equilibrium thickness of about 2 1/8 inches. The oil recovery rate is seen to be somewhat variable.

The data of Table 13 are plotted in Figure 26. The build-up of the oil within the barrier region as identified by the reduction in the distance to the oil head wave and the increasing depth of the oil just inside the barrier is seen to be a very gradual process. The high degree of variation in the oil recovery rate data as shown by the triangular data points is clear. Unfortunately, this scatter in the oil recovery rate data completely masks any differences in oil recovery rate that might be attributed to increased recovery on the backside of the drum. The type of curve that had been expected for oil recovery rate, assuming that the backside recovery was of sufficient magnitude, was a curve having two flat portions, or two horizontal sections. It was expected that the oil recovery rate would increase from zero to some equilibrium value which would hold steady until the oil contained within the barrier region built-up to the point where recovery on the backside of the drum occurred. At this point, it was expected that the oil recovery rate would again start to increase and subsequently level off at a second, higher equilibrium value, which would define the equilibrium level of the oil in the barrier region, and the equilibrium value of backside oil recovery from the barrier region. Unfortunately, for the conditions tested, an oil recovery rate curve of this nature was not obtained.

Table 14 is a summary of the data obtained from a stationary test similar to the test previously described with the thickness of the oil slick increased from the previous 1.27 cm to a thickness of 2.54 cm. In this thicker oil, the oil build-up within the barrier region is seen to increase much more rapidly then was the case summarized in Table 13, with the barrier region entirely covered with oil in a period of three minutes, whereas in the previous case it took 25 to 30 minutes to obtain periodic lapping on the backside of the drum. In this thicker oil slick case, oil was for all practical purposes continuously in contact with the backside of the drum as indicated by the tabulated distance of zero inches from the backside of the drum to the oil head wave. In comparing the depth of the oil just inside the barrier for these two cases, the equilibrium depth for the thicker oil slick is seen to be somewhat more than twice that of the thinner slick, the depth reaching a value of about 5 inches for the 2.54 cm slick thickness, whereas it reached only 2 1/8 inches for the 1.27 cm slick thickness. The oil recovery rate is also higher for the greater slick thickness, shown to be averaged out at about 12 gpm for the 2.54 cm slick thickness case in comparison with the

Figure 26. Plot Of The Barrier Test Data For The Stationary Lockheed Unit Operating At 4 RPM In Open Water And 1.27 CM Of No.2 Fuel Oil (Test No. 68)

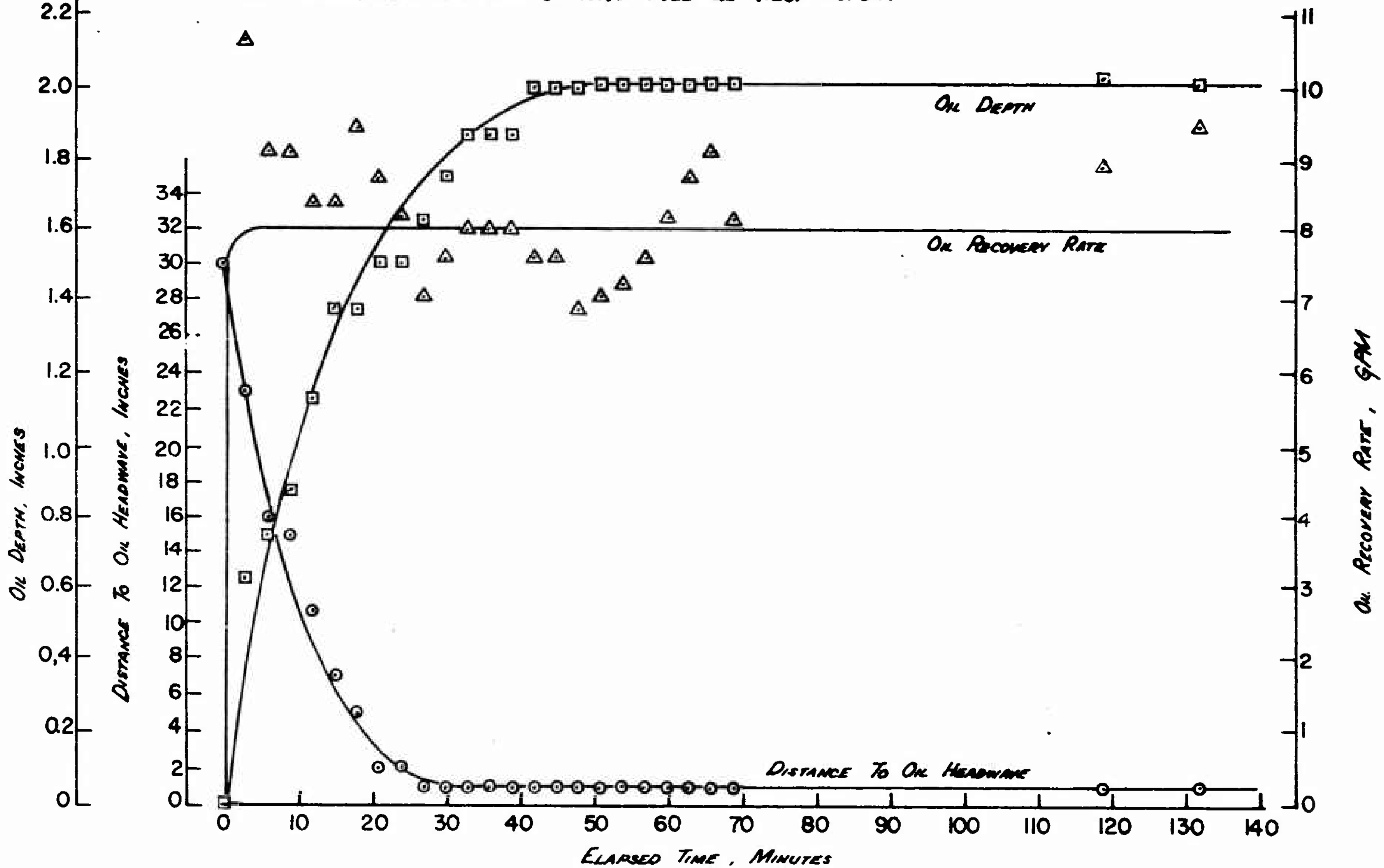


TABLE 14

SUMMARY OF DATA FOR STATIONARY BARRIER TEST
OF THE LOCKHEED UNIT OPERATING AT 3 TO 4 RPM
IN OPEN WATER AND 2.54 cm OF NO. 2 FUEL OIL
(TEST NO. 69)

Elapsed Time min.	Distance to Oil Headwave inches	Depth of Oil at Barrier inches	Oil Recovery Rate gpm
0	27	0	0
2.5	12	2.25	11.4
3	0	2.75	13.3
3.5	0	4.50	14.1
6	0	4.50	14.8
8	0	4.63	10.3
12	0	4.75	9.9
15	0	4.75	9.9
18	0	5.25	13.7
21	0	5.00	10.8
24	0	5.00	10.3
25	Barrier removed		
31	24	1.00	12.9
34	-	-	11.0
36	32	1.00	12.9

average of about 8 gpm for the 1.27 cm slick thickness case. Obviously with this very rapid build-up of oil within the barrier region, the possibility of detecting the expected two plateau type of oil recovery rate versus elapsed time curve was even more remote. Figure 27 is a plot of the oil recovery data obtained during Test 69. Again, the substantial variation in the measured oil recovery rate is clearly shown.

In another attempt to demonstrate the difference in oil recovery rate with and without the barrier in place, as a part of Test 69, the barrier was removed after the test had progressed for 25 minutes. The three data points obtained in the 11 minutes of the test run following removal of the barrier are tabulated in Table 14 and plotted in Figure 27. Again, no clear difference in oil recovery rate can be detected. The differences, if any exist, apparently are still masked by the variation in the oil recovery rate. With the barrier removed, the oil head wave moved back about 2 1/2 feet from the backside of the drum at the waterline with a drum rotation of 3 rpm. At the end of this test, the speed of drum rotation was increased to 8 rpm, with the result that the oil head wave moved still further back to a distance of 6 feet from the backside of the drum.

The data obtained from the moving tests of the Lockheed unit with the barrier installed operating in open water with 1.27 cm No. 2 fuel oil are presented in Table 15. Tests were conducted under three conditions, the first being with the barrier removed, the second consisting of the barrier in place with the stationary or static charge of oil in the barrier region, and a third case where an overcharge of oil was put in the barrier region. To establish the starting point for the static charge case, the Lockheed unit was operated in a stationary mode until the oil depth in the barrier reached a steady value. At this point, without changing the rotation of the drum, the forward drive mechanism was engaged and a test run. For the overcharged situation, a similar procedure was followed whereby the Lockheed unit was operated in a static mode until the oil depth in the barrier reached an equilibrium condition. At that point, the barrier region was overcharged with the external addition of more oil, after which the forward drive system was engaged and the test run. This sequence of tests was intended to evaluate the ability of the unit to recover oil on the backside of the drum from the barrier region. The test results tabulated in Table 15 for a nominal speed of advance of 0.5 fps are plotted in Figure 28. In this figure, the open data points are the data points for the oil recovery rate while the shaded data points are the data obtained for the throughput efficiency. The circular points are for the case with the barrier

FIGURE 27. PLOT OF THE OIL RECOVERY RATE DATA OF TEST No. 69

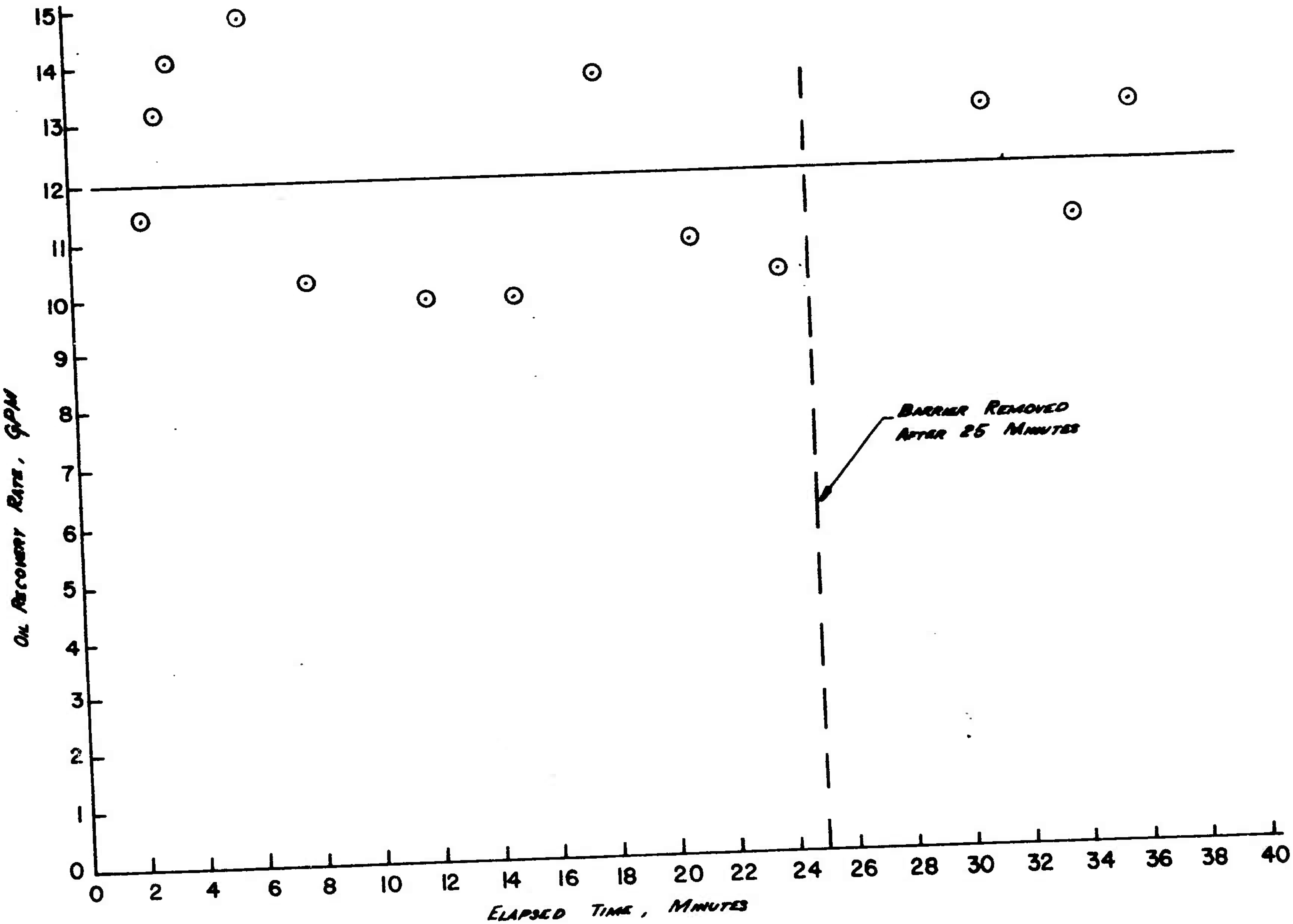
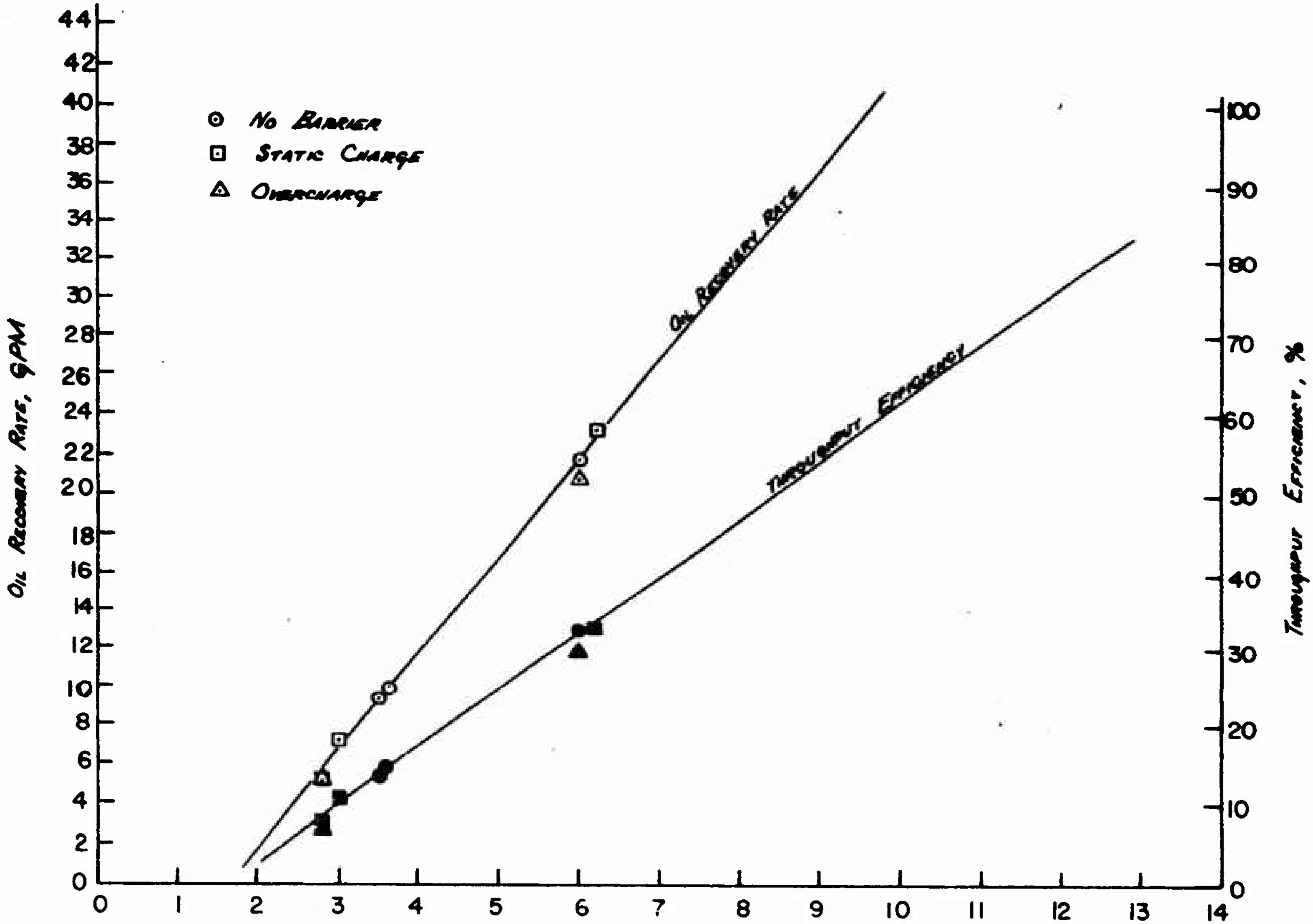


TABLE 15

SUMMARY OF DATA FOR MOVING BARRIER TESTS OF THE LOCKHEED UNIT OPERATING IN OPEN WATER AND 1.27 cm OF NO. 2 FUEL OIL

Target Speed of Advance fps	Actual Speed of Advance fps	Target Drum Rotation rpm	Actual Drum Rotation rpm	Oil Recovery Rate gpm	Throughput Efficiency %	Oil Depth in Barrier Start inches	Oil Depth in Barrier End inches	Test No.	Condition
0.5	0.51	3	3.6	9.73	14.2	N/A	N/A	70	No Barrier
0.5	0.53	3	3.5	9.36	13.3	N/A	N/A	79	No Barrier
0.5	0.50	6	6.0	21.7	32.5	N/A	N/A	71	No Barrier
1.5	1.57	6	6.0	19.5	9.3	N/A	N/A	72	No Barrier
0.5	0.52	3	2.8	5.1	7.4	3.87	5.50	73	Static Charge
0.5	0.52	3	3.0	7.1	10.2	3.75	5.50	80	Static Charge
0.5	0.53	6	6.2	23.2	32.6	3.75	3.50	74	Static Charge
1.5	1.49	6	6.3	22.4	11.3	3.50	3.25	75	Static Charge
0.5	0.54	3	2.8	5.1	7.1	8.00	6.00	76	Overcharge
0.5	0.53	6	6.0	20.8	29.3	7.75	6.50	77	Overcharge
1.5	1.50	6	6.0	20.0	10.0	8.75	4.50	78	Overcharge

Figure 28. Plot Of Moving Barrier Tests Of The Lockheed Unit In Open Water With 1.27 CM Of No. 2 Fuel Oil At A Forward Speed Of 0.5 FPS



removed, the square data points are for the test run with the static charge in the barrier region, and the triangular data points are for the case where the barrier regions had been overcharged with oil. Figure 28 clearly shows that no significant differences in oil recovery rate or throughput efficiency were obtained for the three different conditions tested. On the basis of these tests therefore, it would appear that the presence of the barrier on the unit had a negligible effect on the oil recovery performance of the unit operating in light No. 2 fuel oil.

Referring back to the tabulated data of Table 15 and looking at the data obtained for the nominal 6 rpm drum rotation cases at nominal advance speeds of 0.5 fps and 1.5 fps, it is seen that the recovery rates are about the same for the two values of advance speed, while the throughput efficiency at the higher speed is approximately one-third the throughput efficiency at the lower speed. This indicates that the oil recovery device is limited in its oil recovering capability under these conditions by the drum speed of 6 rpm. Since the change in throughput efficiency is proportional to the change in speed of advance, the unit is obviously not operating at a high enough drum speed to encounter all of the oil that is available to it; in other words, the unit must be pushing oil away from itself as it progresses down the length of the basin.

In summary, the results of the brief tests of the Lockheed unit conducted with the barrier installed behind the drum may be stated as follows:

1. Under the conditions tested, the addition of a barrier installed on the downstream side of the Lockheed oil recovery device does provide for the containment of some oil which would otherwise escape from the device.

2. Oil does build up in the barrier region to the point where it ultimately makes contact with the backside of the drum at which point it is conceivable that the drum could recover oil from the barrier region.

3. Under the conditions tested, no significant improvement in oil recovery rate or throughput efficiency could be detected due to the presence of the barrier. Since oil was never observed escaping from the barrier region, it is probable that the oil recovery rate was slightly increased due to the backside recovery of oil with the barrier present. However, such an increase could not be verified in these tests.

Analysis of the Marco Unit's Performance in Ice

Tables 16 and 17 are summaries of the oil recovery data obtained from the tests conducted with the Marco oil spill recovery device operating in ice infested waters and a 0.73 cm nominal oil slick thickness of crude oil and No. 2 fuel oil respectively. The data summarized in these tables were extracted from Tables 5 and 7. Included in each of the tables is a definition of the test conditions, the actual speed of advance of the unit, the actual speed of the Marco Filterbelt, the oil recovery rate, the unit oil recovery rate defined as the oil recovery rate divided by the 13 inch width of the Filterbelt, the oil recovery efficiency, the throughput efficiency, the nominal oil thickness for the test, and the number of the test. While the original test plan called for the testing of three ice processor modifications in connection with the Marco unit, in actuality, six ice processors were tested in crude oil and four were tested in No. 2 fuel oil. These additional modification tests were related to variations based on the basic active processor concept. The first three ice processing tests with the Marco unit operating in crude oil were conducted as planned. These consisted of testing the static ice processor, followed by a test with a freewheeling ice processor mounted on the boom of the Marco unit, after which the active ice processor was mounted on the boom of the Marco unit. Based on test observations, rather than the reduced data which was unavailable to contribute to the analysis at the time, it appeared that relatively little crude oil was recovered by the Marco device with the active processor mounted directly on the boom of the unit. It was conjectured that the active ice processor was processing the very viscous crude oil along with the ice pieces, thereby minimizing the recovery of oil by the unit. As previously described, the active ice processor installation was then further modified such that it was located approximately 8 feet forward of the Marco boom, with the intention being to allow time for the oil that may have been processed downward with the ice to resurface prior to passage of the Marco boom. Again, based on observations made during the test, it appeared that the screen connecting the active ice processor with the boom of the Marco unit, installed for the purpose of keeping ice out of the region, had a tendency to anchor the very viscous crude oil, thereby preventing it from reaching the suction area of the Marco device. A further modification of the active processor was then made with the intention of minimizing this problem. The modification consisted of widening the screen at the Marco boom end in a uniform fashion such that the separation of the sidewalls of the screen was two feet at the active ice processor and four feet at the boom of the Marco unit. With this widened screen at the boom end, observation indicated that the oil did more readily

TABLE 16

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED WITH THE MARCO DEVICE IN CRUDE OIL AND ICE-INFESTED WATERS

Condition	Speed of Advance fps	Speed of Belt fps	Oil Recovery Rate gpm	Unit Oil Recovery Rate gpm/ft	Oil Recovery Efficiency %	Throughput Efficiency %	Oil Thickness cm	Test No.
Unmodified	0.47	4	1.7	1.57	13	31	0.73	16
Static Processor	0.51	4	1.8	1.66	19	30	0.73	7
Freewheeling Processor	0.49	4	1.5	1.38	26	26	0.73	9
Close Active Processor	0.49	4	2.2	2.03	30	38	0.73	11
Extended Active Processor	0.48	4	1.5	1.38	9	28	0.73	18
Widened Screen E.A.P.	0.34	4	1.8	1.66	17	46	0.73	20
W.S.E.A.P. - No Pump	0.49	4	2.0	1.85	12	36	0.73	21
Widened Screen E.A.P.	1.16	4	11.8	10.89	47	87	0.73	23
Widened Screen E.A.P.	0.49	1	2.9	2.68	54	51	0.73	22
Widened Screen E.A.P.	0.47	4	5.1	4.71	25	54	1.27	24

TABLE 17

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED WITH THE MARCO DEVICE IN NO. 2 FUEL OIL AND ICE-INFESTED WATERS

Condition	Speed of Advance fps	Speed of Belt fps	Oil Recovery Rate gpm	Unit Oil Recovery Rate gpm/ft	Oil Recovery Efficiency %	Throughput Efficiency %	Oil Thickness cm	Test No.
Unmodified	0.47	4	3.9	3.60	19	71	0.73	67
Static Processor	0.51	4	5.0	4.62	24	84	0.73	66
Freewheeling Processor	0.50	4	3.0	2.77	17	52	0.73	64
Close Active Processor	0.49	4	5.0	4.62	24	89	0.73	62
Widened Screen E.A.P.	0.48	4	6.2	5.72	41	111	0.73	49
Widened Screen E.A.P.	0.88	4	2.0	1.85	25	19	0.73	51
Widened Screen E.A.P.	1.32	4	3.4	3.14	30	22	0.73	52
Widened Screen E.A.P.	0.43	1.2	0.8	0.74	50	16	0.73	55
Widened Screen E.A.P.	0.45	1.5	1.02	0.94	36	19	0.73	56
Widened Screen E.A.P.	0.48	2.5	4.5	4.15	34	80	0.73	56A
Widened Screen E.A.P.	0.49	4	5.5	5.08	59	55	1.27	59

free itself from the screen and proceed to the suction area of the Marco boom from where it could be recovered. It was also speculated that if sufficient length were available to test a screened area having a shallow angle extended further to a point, much of the same effect may result without the added complexity of the active ice processor. The active ice processor, in effect, makes it possible to reduce the great length otherwise required to something more reasonable as far as the test facility is concerned. This length restriction may not be present in field applications. During this series of events with further modifications of the active ice processor, the question also arose as to whether or not the induction pump of the Marco unit was contributing to the oil recovery of the unit with this very heavy crude oil. In order to answer this question, one test was conducted in crude oil with the widened screen extended active processor in place and the induction pump inoperative. Because of these three additional ice processing tests, the tests directed towards determining the performance variation of the unit with variation in speed of advance and belt speed were reduced from the planned four tests to an actual two tests. Only two data points were, therefore, obtained for the performance variation of the unit with speed of advance and with belt speed. Finally, the last row of data in Table 16 is for the single test conducted in the 1.27 cm nominal thickness of crude oil.

The series of tests run with the Marco unit in No. 2 fuel oil varied from both the planned test program and the series actually conducted in crude oil. Tests were conducted in No. 2 fuel oil with the static ice processor, the freewheeling ice processor, the close-coupled active processor, and the widened screen extended active processor, this last being the case for which the performance variation tests were run in both crude oil and No. 2 fuel oil. In addition, three data points were obtained to evaluate the variation in oil recovery performance with variation of speed of advance, and four data points were obtained to evaluate the oil recovery performance of the unit as a function of the speed of the Filterbelt. The last row of data in Table 17 is the single data point obtained in ice infested waters with a nominal oil slick thickness of 1.27 cm of No. 2 fuel oil.

Figure 29 is a display of the results obtained from the modification tests conducted with the Marco unit in both crude oil and No. 2 fuel oil in an attempt to facilitate a comparison of the different ice processing techniques tested. The results displayed include the oil recovery rate, the oil recovery efficiency, and the throughput efficiency, in a semi-graphical manner. The performance for each case in crude oil is given on the left hand side, and the performance in No. 2 fuel oil is presented on the right hand side.

FIGURE 29. DISPLAY OF RESULTS FROM MODIFICATION TESTS CONDUCTED WITH MARCO UNIT.

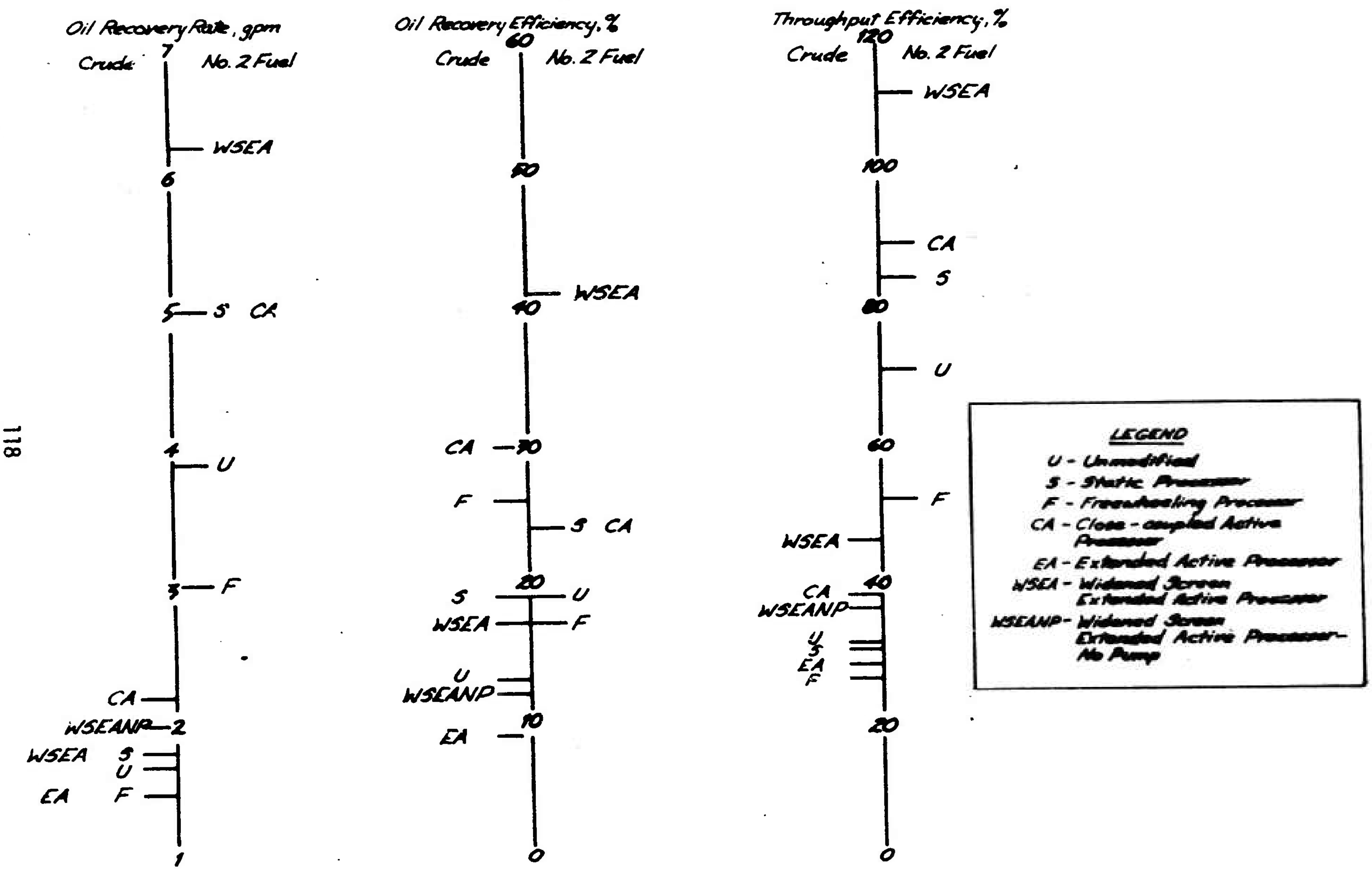


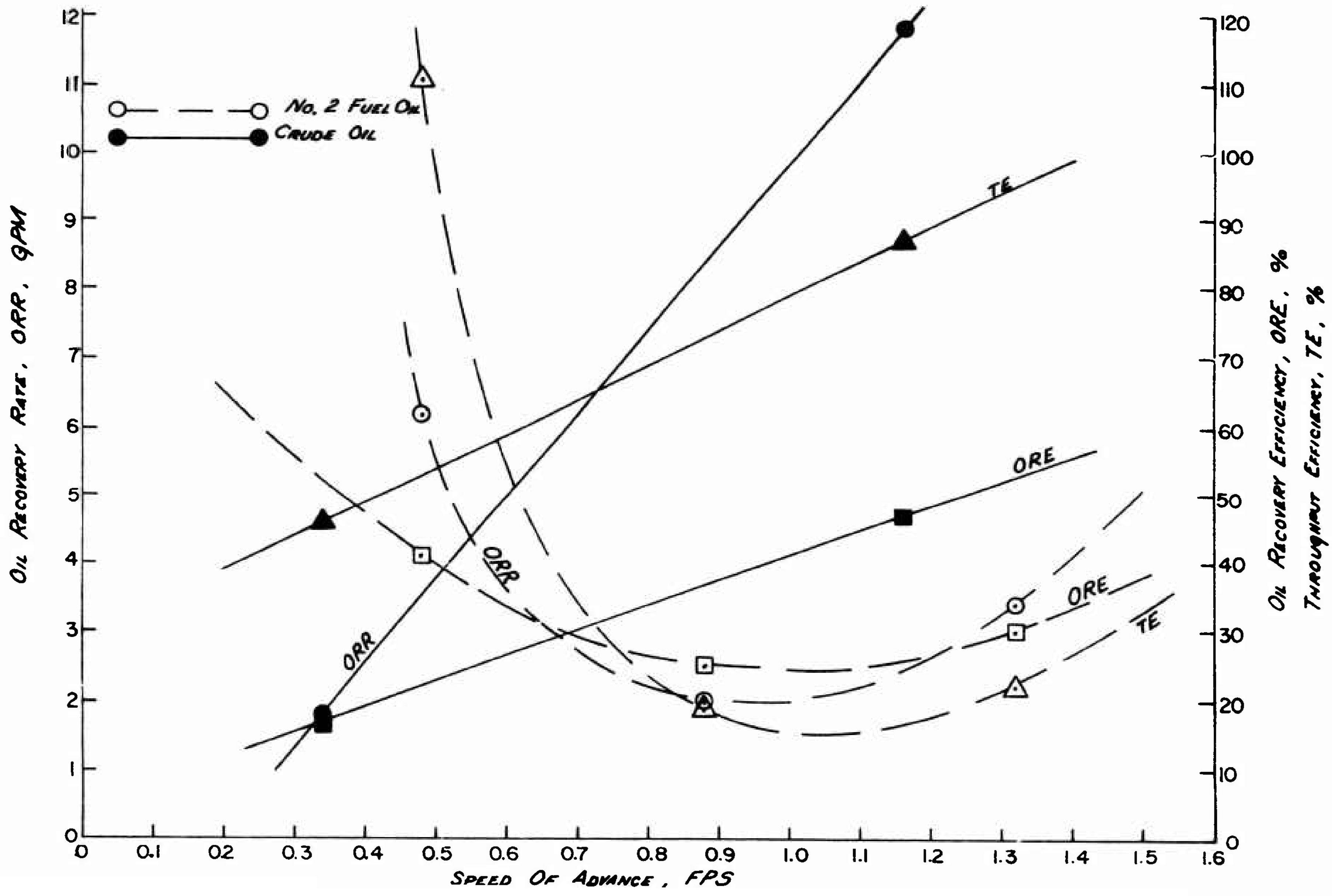
Figure 29 graphically displays the relatively small spread in oil recovery rate achieved with the Marco unit regardless of which, if any, ice processing technique was employed with it when operating in the very viscous crude oil. The oil recovery rates are seen to span a range from 1.5 to 2.2 gpm. In contrast to the visual observations made during the tests themselves, the oil recovery rates achieved with the close-coupled active processor, and the widened screen processor without the induction pump operating, were somewhat improved over the other conditions tested. It is somewhat questionable, however, as to whether the small differences measured in crude oil for the various modifications are significant, especially in view of their basis upon a single data point. In reviewing the oil recovery efficiency obtained from the crude oil tests, it is again somewhat surprising to see the close-coupled active processor providing the best performance. One would expect the oil recovery efficiency to be somewhat higher for the freewheeling processor, the static processor, and the unmodified case, relative to the active processor cases, since with the active processor there is more of a likelihood of churning the oil and water to a considerable degree before it is recovered by the Filterbelt of the Marco unit. As for the throughput efficiency obtained from the tests conducted in crude oil, the best performance is delivered with the widened screen extended active processor in place.

Reviewing the No. 2 fuel oil side of the charts in Figure 29, the use of the widened screen extended active processor appears to have a decided advantage over the other ice processors tested in all three performance measures of oil recovery rate, oil recovery efficiency, and throughput efficiency. The static ice processor and the close-coupled active processor then give very similar results, having identical oil recovery rates and oil recovery efficiencies, with the close-coupled active ice processor having a slight edge over the static ice processor in throughput efficiency. Considering the extreme simplicity of the static ice processor, and the relative complexity of the active ice processor, the static ice processor would certainly be designated for use in lighter oils as the preferred processor in any choice between the two. The freewheeling ice processor is seen to give the poorest performance of all the units tested, including the unmodified Marco device. This standing of the freewheeling processor reflects that fact that this processor did not operate as planned in either the crude oil test or the No. 2 fuel oil test since it did not rotate as intended over the entire length of the run. Based on observations of the test, it is felt that the freewheeling processor still has merit in concept, and is worthy of further condsideration, however, the diameter of the processor and the elevation of the centerline of the processor

above the floating ice pieces must both be significantly increased. While not proven, it is also possible that ice may have become jammed between the ribs of the freewheeling processor and the screen extending between the processor and the boom of the Marco unit. This potential problem could be minimized by the use of more closely spaced, thinner bars for the cage of the processor, or through the use of a mesh material rather than straps.

Figure 30 is a plot of the oil recovery performance of the modified Marco oil spill recovery device as a function of the speed of advance of the device. All of the tests from which the data displayed in Figure 30 were obtained were conducted with the widened screen extended active processor in place. Following the convention established previously for the Lockheed tests, the test results obtained for operation in No. 2 fuel oil are shown as open data points with dashed lines, while the crude oil test results are shown as solid data points with solid lines. As previously mentioned, only two data points were obtained for the performance variation series in crude oil, consequently straight lines are shown in Figure 30 for the curde oil test results, with the acknowledgement that a linear relationship is unlikely. The crude oil test results show the oil recovery rate to increase significantly with increasing speed of advance, along with a corresponding improvement in oil recovery efficiency and throughput efficiency. This improved oil recovery rate with increasing speed of advance could possibly be attributed to a reduced tendency of the very viscous crude oil to adhere to the mesh sides of the ice barrier screen, and to the possibility that the belt of the Marco unit is more attuned to recovering the crude oil in a continuous strip rather than in occasional snatches at the higher forward speed. The latter reasoning would also incorporate an improvement in oil recovery efficiency and throughput efficiency, as is seen to be the case. The test results obtained for operation in the lighter No. 2 fuel oil are more difficult to rationalize. All three performance measures of oil recovery rate, oil recovery efficiency, and throughput efficiency exhibit a minimum point when plotted as a function of speed of advance. At the low end of the speed range, it is not surprising to see the oil recovery performance improve in the light No. 2 fuel oil, since this light oil distributes itself very rapidly and easily through the broken ice cover, whereas the more viscous crude oil has little tendency to redistribute to a uniform oil slick thickness in broken ice cover. As a result, as the speed of advance is reduced, the Marco unit has a tendency, because of the operation of the induction pump, to draw more and more oil from surrounding areas as opposed to limiting its suction to the swath width. It is because of this aspect of the unit's operation that throughput efficiencies in excess of 100% can be obtained. Values

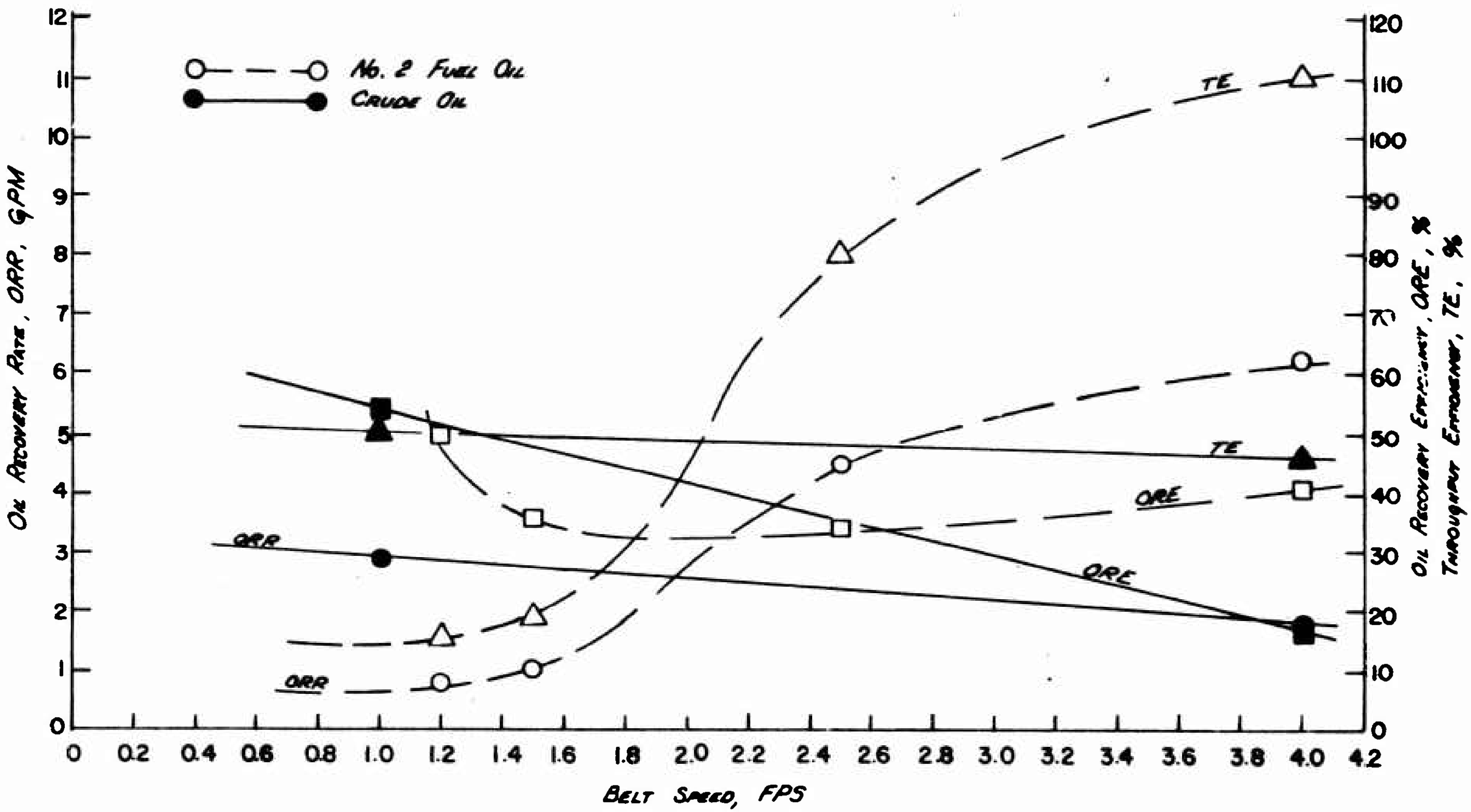
FIGURE 30. PERFORMANCE OF THE MODIFIED MARCO UNIT IN ICE AS A FUNCTION OF SPEED OF ADVANCE



of throughput efficiency greater than 100% simply indicate that the Marco unit not only recovered the oil directly in its path, but in addition, pulled in some oil from beyond the exact sweep width of the unit. In this speed range, it is also not unlikely to see an improvement in oil recovery efficiency, since the induction pump causes a draw-down of the surface at the suction point of the Filterbelt. This draw-down would tend to fill with additional oil drawn in from the surrounding area; consequently, the ratio of the oil to water pulled through the Filterbelt by the induction pump should be increased, and a higher value of oil recovery efficiency should be obtained. Looking at the upper range of speed of advance, no convincing rationale can be developed for the improvement in oil recovery performance with increasing speed of advance. One possible, but not necessarily convincing, explanation is the possibly related action of the active ice processor in tending to gather oil to the recovery device. As the forward speed of the unit is increased, the speed of the active ice processor is correspondingly increased. It is possible that the increased speed of rotation of the active ice processor could tend to cause a draw-down at the ice processor, similar to the draw-down caused by the induction pump of the Marco unit at the belt, which would then have a tendency to fill with oil from the surrounding area with the result being an increased feed of the oil to the Marco belt. Again, a corresponding improvement in oil recovery efficiency and throughput efficiency would be expected, and this is seen to be the case. Further testing would be required to more completely define the variation in oil recovery performance as a function of speed of advance of the Marco unit and to provide additional insight into the mechanism behind the variation in performance.

Figure 31 is a plot of the variation in performance of the modified Marco unit as measured by oil recovery rate, oil recovery efficiency and throughput efficiency, as a function of the belt speed. As was the case with the forward speed variation tests, the belt speed variation tests were conducted with the widened screen extended active processor in place. Since only two data points were obtained in the crude oil test series, the straight lines connecting these two points are indicative only of trends and not of functional relationships. The results show that the oil recovery rate decreases somewhat as the speed of the Filterbelt increases, with a corresponding small decrease in throughput efficiency and a greater decrease in oil recovery efficiency. In the case of the very viscous crude oil, these curves could again reflect the effect of recovering the oil in a continuous manner as opposed to snatching off strips of the crude oil in rapid fashion. The slower belt speed would obviously correspond to an attempt at recovering a continuous strip, or layer, of the very viscous crude oil on the Filterbelt.

Figure 31. Performance Of The Modified Marco Unit In Ice As A Function Of Belt Speed



As the belt speed increased beyond the value corresponding to a matched forward speed of the unit, the recovery of a continuous strip of oil would change into the recovery of intermittent snatches of the oil. Again it is important to distinguish between the recovery of extremely viscous oils through the conveyor effect with the Marco unit, and the recovery of thin oils through absorption into the pores of the Filterbelt of the Marco unit. A review of the test results plotted for operation in the lighter No. 2 fuel oil shows that the oil recovery rate and the throughput efficiency both increase as the belt speed is increased. In contrast to this, the oil recovery efficiency curve initially decreases as the belt speed is increased, reaches a minimum at a belt speed of about 2 fps, and then increases with further increase in belt speed. For operation in light oils, which must be recovered by the Marco device through absorption into the pores of the Filterbelt rather than through the layering, or conveyor, effect on the surface of the Filterbelt, and assuming that the Filterbelt is not saturated with oil, one would expect the oil recovery rate to increase as the belt speed is increased up to the point where the belt either becomes saturated with oil or the belt is recovering all of the oil that is present to recover. At the lower values of belt speed, Figure 31 shows the low oil recovery rates to correspond to a low value of throughput efficiency. This combination can be interpreted as demonstrating that more oil was present, and available for recovery, than the unit could recover at that belt speed; consequently, a substantial amount of oil was being passed up by the Marco unit. As the belt speed was increased, the unit was able to recover more of the oil that was made available to it, as shown by the increasing oil recovery rate and the increasing throughput efficiency. The pores of the Filterbelt are likely saturated with oil under these conditions; that is, the belt is holding all of the oil that it is capable of holding, and the recovery is being limited by the slow speed of rotation of the belt. As the belt speed is further increased, the throughput efficiency eventually reaches a value of 100%, at which point the unit is recovering all of the oil available to it in the swath width. At this point, a further increase in belt speed increases the oil recovery rate and the throughput efficiency to still greater values but at a reducing rate. This trend could reflect the fact that the unit is now requiring oil from beyond the swath width, and it is conjectured that the Filterbelt is still saturated with oil at this condition. As the belt speed is further increased, the oil recovery rate is seen to level off at a constant value, indicating that the limiting factor changes from one of matching the belt speed to the available oil, to the limitation based on the availability of oil directly in the path of the unit and capable of being drawn in from beyond the swath width of the unit. The leveling off of the throughput

efficiency curve would indicate that for the conditions tested, the unit is capable of drawing in little more than 110% of the oil directly encountered in its sweep path.

A comparison of the data points obtained for the test conducted in the higher nominal oil thickness of 1.27 cm with the test conducted in the minimum oil slick thickness of 0.73 cm further demonstrates the performance differences achieved with the Marco device for different types of oil. Referring back to Table 16, and comparing the results of Test 20 with the results of the higher oil thickness run of Test 24, the oil recovery rate is seen to be nearly tripled for the higher thickness case. Some of this increase can be attributed to the somewhat higher throughput efficiency for the higher thickness case, however, this comparison primarily demonstrates again the influence of the conveyor effect on the performance of the Marco unit when operated in extremely viscous oil. One could postulate that over a reasonable range of oil slick thicknesses, the oil recovery rate of the Marco unit would generally increase as the slick thickness increased based upon the conveyor effect providing the primary mode of recovery. In comparison to this, the data obtained for the same two cases in No. 2 fuel oil, as listed for Tests 49 and 59 in Table 17, show that the oil recovery rate is essentially the same for both cases, while the throughput efficiency has been approximately halved for the higher thickness case. This then indicates that the Marco Filterbelt is saturated under these condictions and can recover no greater amount of oil regardless of how thick the oil slick is. The indication is that in both of these tests, the pores of the Filterbelt were saturated with No. 2 fuel oil.

The major conclusions to be drawn from these tests of the Marco oil recovery device in ice infested waters are then as follows:

1. The oil recovery performance of the unit varies substantially with operating conditions including the oil type, oil thickness, belt speed, and speed of advance. The parameters under the control of the operator, the belt speed and the speed of advance, must be carefully selected to obtain optimum oil recovery performance with the Marco device.

2. The oil recovery performance of the Marco device in broken ice cover can be improved considerably through the addition of devices to process the ice under or around the oil recovery unit, such that the suction area of the recovery unit is relatively ice free and can recover oil in essentially an open water mode of operation.

Analysis of Tests of Other Units in Ice

The tests planned for the OSI Skimmer, the JBF DIP, and the Oil Mop oil spill recovery devices were basic in nature and were intended to evaluate in a general way the applicability of these devices for use in recovering oil spills in ice infested waters. The tests conducted with the OSI, JBF, and Oil Mop devices are then more comparable to the basic evaluation tests of the Phase I program conducted with the Lockheed and Marco devices. The purpose of these tests was to test and evaluate the devices in their off-the-shelf condition, with no special procedures or hardware modifications incorporated for their use in ice infested waters.

Table 18 is a summary of the oil recovery data obtained from tests conducted with the OSI and JBF devices in a 0.73 cm nominal thickness of crude oil in ice infested water. Both devices were tested from one end of the model basin to the middle with propulsion supplied by the basin's main carriage through a tether arrangement connecting the device to the main carriage. In addition, the JBF unit was tested in the self-propelled mode. Both units were installed in a free floating manner in the model basin, rather than being rigidly mounted to the carriage. The operating manual supplied with the OSI Skimmer recommends a towing speed range of 0.7 to 1.0 knots, equivalent to about 1.2 to 1.7 fps. Since this device is a dynamic recovery device, that is, it depends on a relative velocity between the oil slick and the oil recovery device to successfully recover the oil, it was important to ensure that the speed of advance was adequate; consequently, the upper end of the speed range was selected as the target speed, with the actual speed of advance measured as 1.68 fps. As shown in Table 18, both the oil recovery efficiency and throughput efficiency obtained with the OSI device were extremely low. As the test proceeded, the OSI unit gathered a mass of broken ice pieces in its intake region. This mass of ice appeared to push additional ice, and the oil surrounding the ice pieces, away from the unit. As a result, very little oil was available to the unit at its suction area, and in general, the unmodified OSI device was judged to be relatively unsuitable for operation in such ice conditions. Figure 32 is a photograph of the OSI Skimmer installed in the model basin prior to testing. The likelihood of blockage of the inlet area due to the presence of ice pieces is obviously very high. The effect of such blockage is quite severe for very heavy oil such as the very viscous crude oil tested in this program. It is likely that the detrimental effect of such blockage would be somewhat reduced in the lighter oils. Since much of the body of the OSI Skimmer is made of flexible fabric, there was some question as to the performance of this fabric in the broken ice field. Based on the

TABLE 18

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED WITH THE OSI AND JBF DEVICES IN 0.73 cm OF CRUDE OIL AND ICE-INFESTED WATERS

Device	Condition	Speed of Advance fps	Oil Recovery Rate gpm	Oil Recovery Efficiency %	Throughput Efficiency %	Test No.	Comments
OSI	Tethered	1.68	2.3	3	5	29	
JBF	Tethered	0.58	6.4	30	49	30	
JBF	Self-propelled	0	0	0	0	31	Propulsion inadequate in ice.

FIGURE 32. PHOTOGRAPH OF THE OSI SKIMMER READIED FOR TESTING IN ICE INFESTED WATER AND CRUDE OIL.

very limited experience of one test run, no problems were experienced with the flexible body of the OSI Skimmer in the broken ice field.

The operations manual supplied with the JBF DIP unit recommends a forward speed in the range of 1/4 to 1/2 knot, corresponding roughly to 0.4 to 0.8 fps. A target speed of advance for the tethered run was, therefore, selected as 0.5 fps, with the actual measured speed of advance during the test determined to be 0.58 fps. Prior to installing the JBF DIP in the model basin, the easily removable debris rake mounted on the front of the unit was removed, since it was likely that this debris rake would simply clog up with broken ice pieces in much the same manner that the suction area of the OSI Skimmer became clogged. There was speculation that the movable belt of the JBF unit could possibly induce some processing of the broken ice pieces, however, this was not found to be the case. The very smooth surface of the belt simply rode on the ice encountering it, without processing the ice down and under the unit. As a result, the ice pieces for the most part stayed in place in front of the unit, appearing to push some other ice pieces and some oil away from the suction area of the unit. The blockage in front of the JBF unit did not , however, appear to be as permanent as that in front of the OSI Skimmer. As a result, a greater oil recovery was measured in the JBF test. Table 18 shows that the oil recovery rate obtained with the JBF unit was 6.4 gpm at an oil recovery efficiency of 30% and a throughput efficiency of 49%. This oil recovery performance was somewhat greater than expectations based upon test observations, and apparently the drawing capability of the moving belt of the JBF unit assisted in achieving this oil recovery performance.

At the conclusion of the tethered test with the JBF DIP, a second test was planned with the JBF unit using the installed propulsion system. This propulsion system, as shown in the photograph of Figure 34, is no doubt adequate for use in still open water applications, but it was substantially underpowered for use in the 95% ice coverage of this test program. As a result, zero forward motion was obtained with the installed propulsion system. The only movement that could be imparted to the device with its installed propulsion was a side-ways swinging achieved by alternating the power to the two screws.

As a result of these two tests performed with the JBF DIP, it was judged that while the unit was capable of recovering oil in the tethered mode in ice infested waters, these operating conditions were

FIGURE 33. PHOTOGRAPH OF THE JBF DIP READIED FOR TESTING IN ICE INFESTED WATER AND CRUDE OIL.

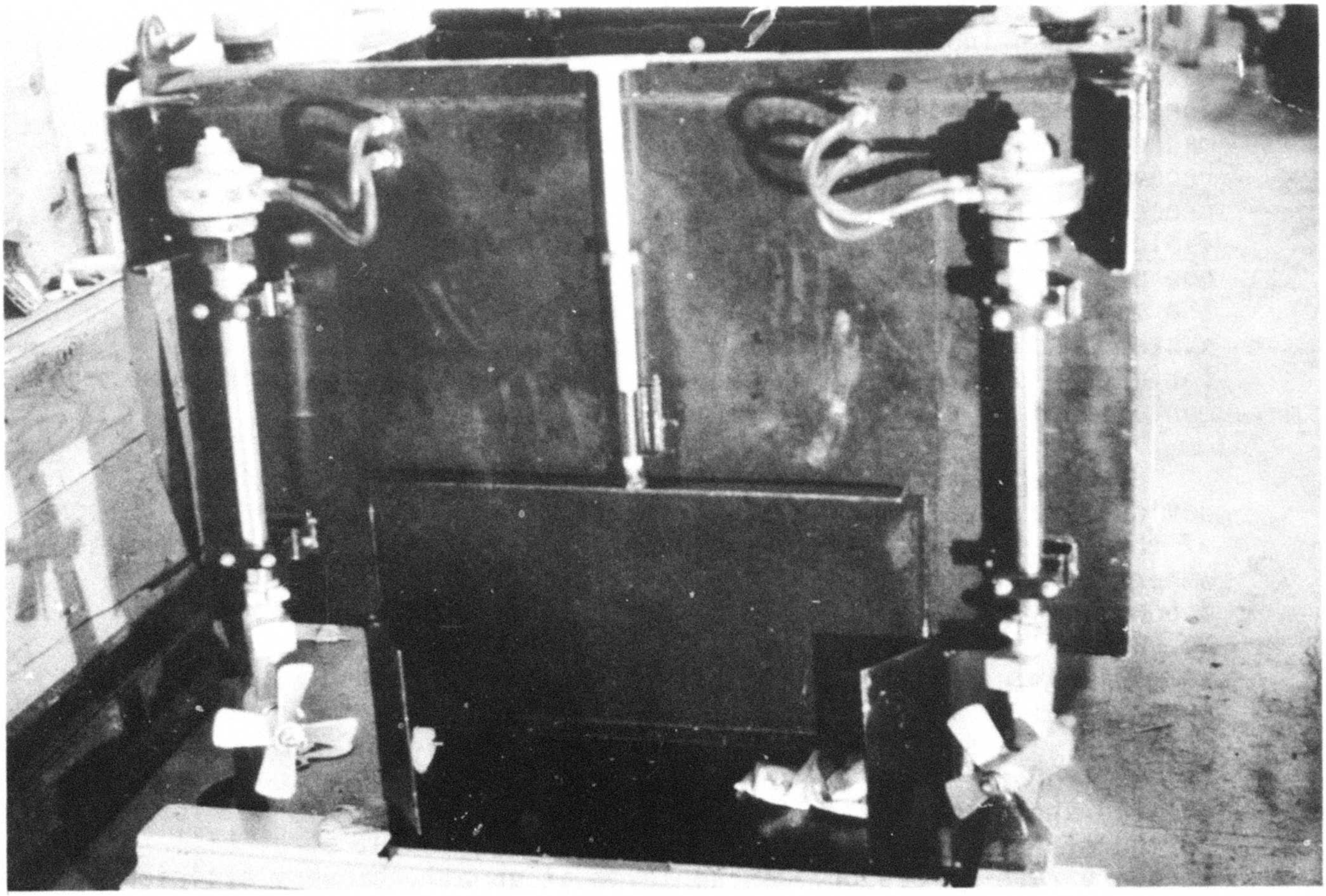


FIGURE 34. STERN VIEW OF THE JBF DIP SHOWING THE INSTALLED PROPULSION SYSTEM.

certainly not well adapted to the capabilities of the device. It is reasonable to expect, however, that the oil recovery rate of the device could be increased in lighter oils, since they would tend to find their way through the broken ice pieces to the suction area of the unit much more readily than does the very viscous crude oil.

It is important to note that the tests of both the OSI and the JBF units were elementary in nature and no effort was devoted towards adapting or modifying the units for operation in ice infested waters. There is little doubt that these units could be adapted for successful operation in ice infested waters in much the same manner as was done in this program with the Marco oil spill recovery device. With this approach, the problem becomes one of ice processing in general and separating the oil from the broken ice field in the case of very viscous oils. The problem then becomes one of the designing a suitable ice processing system and employing the most favorable oil recovery device with the ice processing system based upon an evaluation of the suitability of the device for use in open water with consideration given to other environmental conditions.

The tests conducted with the Oil Mop oil spill recovery device were basic in nature, having as their objective the evaluation of the unit for application in recovering oil spills in ice infested waters in an unmodified, off-the-shelf condition. Four tests were conducted with the Oil Mop device, three in crude oil and one in No. 2 fuel oil. The oil recovery data obtained from these tests are summarized in Table 19. The first test was conducted with the Oil Mop operating in a 1.27 cm nominal thickness of crude oil in ice infested waters. The Oil Mop wringer device was located just above the wall of the model basin on one side, and the idler pulley was located approximately 35 feet away. The first test was run for a period of 17 minutes and, as indicated in Table 19, a net oil recovery rate of 0.9 gpm was achieved at an oil recovery efficiency of 97%. The throughput efficiency of 300% tabulated for this test indicates that the Oil Mop rope did draw in oil from the surrounding area beyond that of the immediate sweep width, defined as the width of the two legs of the rope. Prior to conducting this test in the extremely viscous crude oil, there was some question as to whether or not the unit would be capable of drawing any oil from beyond its immediate contact area. As indicated by the data, the unit was capable of drawing in additional oil. Also observed was the ability of the rope of the Oil Mop to work its way into the spaces between ice pieces where the oil was located. Test observations indicated that the oil recovery rate was very high at the start of the test, falling considerably near the end of the test as would be expected. A subsequent test was planned to obtain quantitative

TABLE 19

SUMMARY OF OIL RECOVERY DATA FOR TESTS CONDUCTED WITH THE OIL MOP DEVICE IN ICE-INFESTED WATERS

Oil Type	Oil Thickness cm	Test Condition	Elapsed Time min.	Oil Recovery Rate gpm	Oil Recovery Efficiency %	Throughput Efficiency %	Test No.
Crude	1.27	Stationary, measured total recovery	17	0.9	97	300	26
Crude	1.27	Idler shifted, measured total recovery	14	0.6	95	N/A	27
Crude	0.73	Stationary, rate sampled at intervals	1	1.37	96	N/A	28
			15	0.71	96	N/A	
			30	0.34	96	N/A	
			47	0.17	96	N/A	
			60	0.13	96	1112	
#2	1.27	Stationary, measured total recovery	60	0.08	100	65	61

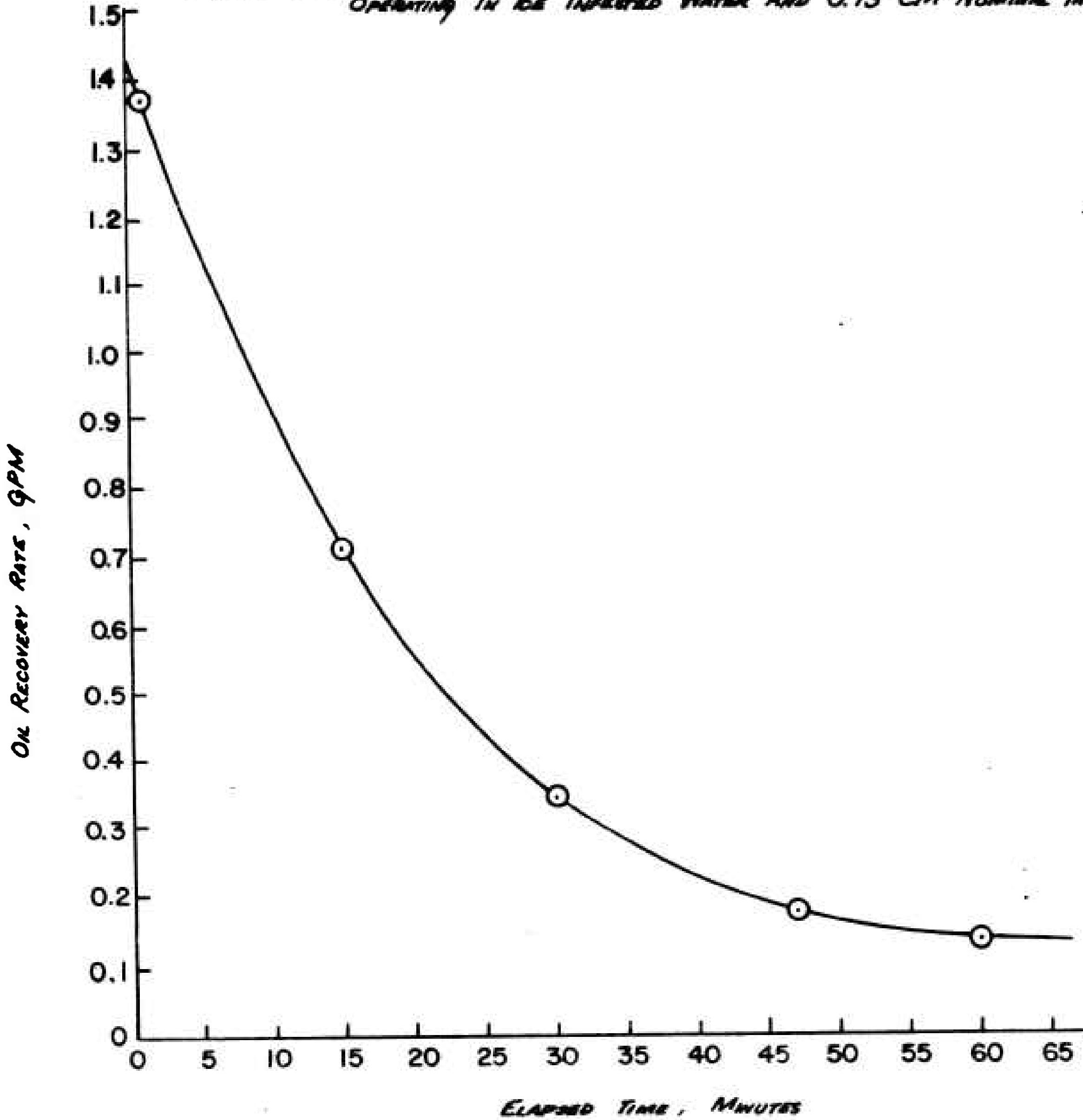
information on the variation in oil recovery rate as a function of time in the very viscous crude oil. Removal of this very viscous crude oil from the rope at the wringer appeared to be no problem.

In order to get an additional feel for how the Oil Mop unit might be applied in recovering oil spills in broken ice cover, a second test was conducted essentially consisting of a continuation of the first test. In the second test, the idler pulley of the Oil Mop unit was shifted a linear distance of approximately 1.4 feet at 2 minute intervals. The average oil recovery obtained in this test was 0.6 gpm at an oil recovery efficiency of 95%. This test demonstrated that moving the idler pulley of the Oil Mop unit is a relatively easy process, and that the readjustment of the rope of the unit to each movement of the idler pulley is accomplished with no difficulty, even in the broken ice field of this test program. The rope of the Oil Mop unit easily rode up and over any ice pieces encountered during this movement and then tended to settle in the spaces between ice pieces again, where it would stay until the idler pulley was again shifted.

The third test conducted with the Oil Mop device in crude oil was directed at determining the variation in oil recovery rate as a function of time. This test was conducted in the minimum thickness of crude oil, that is, a 0.73 cm nominal thickness. The data are summarized in Table 19 and plotted in Figure 35. The oil recovery rate as determined by sampling at intervals is seen to approach 1.5 gpm at the start of the test and levels off at approximately 0.1 gpm after an hour of operation. For oil that would flow more readily between the broken ice pieces, the oil recovery rate would be expected to decrease more slowly than was the case measured in this very viscous crude oil, which had little tendency to redistribute itself between the broken ice pieces.

Because of this very promising performance in the crude oil tests, the Oil Mop device was also tested in No. 2 fuel oil. The oil recovery results obtained in the very light No. 2 fuel oil were, however, disappointing, since the oil recovery rate obtained was only 0.08 gpm. Apparently, the Oil Mop is more favorably inclined towards oils more viscous than No. 2 fuel oil. Consequently, while the Oil Mop device would seem to be well adapted to recovering medium and heavy oil in either open water or in broken ice cover, the unit does not give good oil recovery performance for lighter oils such as No. 2 fuel oil. The Oil Mop unit is also appealing in that the oil recovery efficiency obtained is consistently high, ranging from 95% to 100% in this test program. The separation of water from the oil, and the rope material, appears to occur primarily during the vertical lift of the rope from the water surface. This vertical

FIGURE 35. PLOT OF OIL RECOVERY RATE VS ELAPSED TIME FOR THE OIL MOP DEVICE OPERATING IN ICE INFESTED WATER AND 0.73 CM NOMINAL THICKNESS OF CRUDE OIL



lift was about 1 to 1.5 feet in this test program and, as the belt moved at an angle from the water surface up to the squeeze rollers, most of the surface coating of water on the rope material and on the collected oil had a tendency to drain free. Figure 36 is a photograph of the Oil Mop unit undergoing testing in No. 2 fuel oil in the model basin.

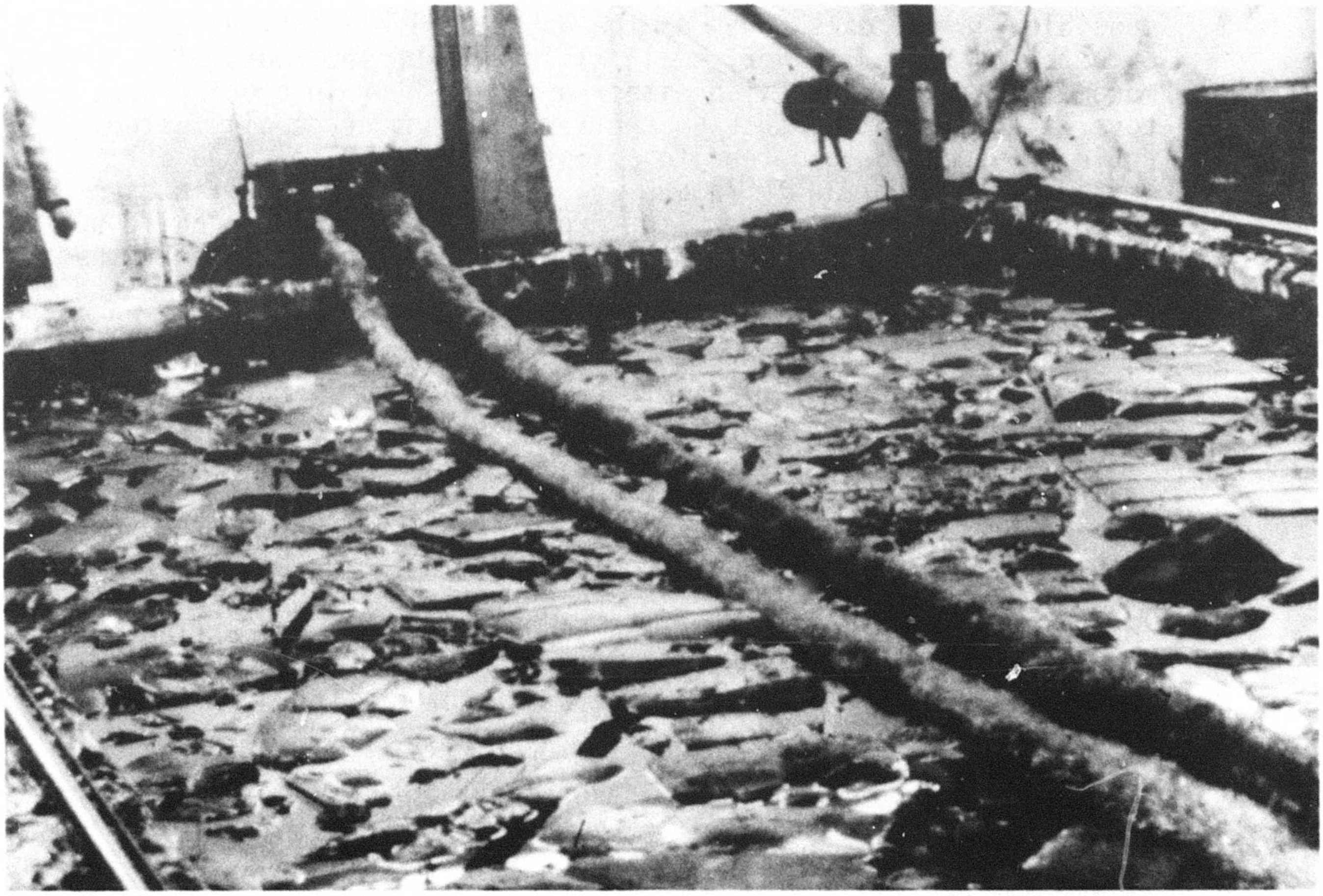


FIGURE 36. PHOTOGRAPH OF THE OIL MOP OPERATING IN NO. 2 FUEL OIL.

CONCLUSIONS

The major conclusions which can be drawn from this program are as follows:

1. Tests directed toward determining the natural slick thickness of No. 2 fuel oil and a crude oil resembling Prudhoe Bay crude at low temperatures in open water and in broken ice cover indicated that a wide variation in natural oil slick thickness is possible. Light oils, such as the No. 2 fuel oil tested, could be expected to spread to very small slick thicknesses, possibly a monomolecular thickness, in either open water or in broken ice cover. Heavier oils, such as the very viscous crude oil tested, could be expected to spread to a lesser extent. The crude oil tested at 32°F spread to an average thickness of 0.73 cm in open water. In broken ice cover, the crude oil thickness can build up to at least several inches, being contained to some extent by the broken ice cover.

2. For tests conducted in open water at 32°F with 0.73 cm and 1.27 cm of No. 2 fuel oil and crude oil, oil recovery rates ranging from 15 to 37 gpm were obtained with the Lockheed unit at oil recovery efficiencies ranging from 62 to 98% and throughput efficiencies ranging from 48 to 63%. For the Marco unit, oil recovery rates ranged from 6 to 10 gpm at oil recovery efficiencies ranging from 26 to 46% and throughput efficiencies ranging from 57 to 118%. Throughput efficiencies greater than 100% are possible for the Marco unit due to the suction action of the induction pump. Corresponding unit oil recovery rates for operation in open water ranged from 2 to 5 gpm per foot of device width for the Lockheed unit and 5 to 9 gpm per foot of device width for the Marco unit.

3. The performance variation tests conducted in this program in broken ice cover to give some indication of the variation in oil recovery performance of the Lockheed unit as a result of variation in forward speed and drum speed, and the performance variation of the Marco unit due to variation in forward speed and belt speed, indicate that the performance of both devices is highly dependent on oil type and operating conditions. For example, for tests of the modified Marco unit, oil recovery performance improved with an increase in belt speed in No. 2 fuel oil, while oil recovery performance declined in crude oil with an increase in belt speed. The achievement of optimum oil recovery performance in the field will therefore be highly dependent upon the operator's ability to match operator controlled variables to operating conditions beyond his control.

4. Problems associated with operating the Lockheed unit in broken ice cover identified in the Phase I program were success-

fully eliminated in the Phase II program. The problems of vane-end bending due to ice/vane interaction and ice jamming between the stationary frame of the unit and the rotating drum were eliminated through the installation of protective guards below the waterline. The problem of dependably removing the oil/ice/water mixture from the very small sump of the Lockheed unit at a rate sufficient to prevent backflow into the drum of the unit was solved through the use of a custom fabricated screw pump.

5. The results of this test program clearly show that the oil recovery rate, oil recovery efficiency, and throughput efficiency could be improved through a reduction in the number of vanes installed on the Lockheed unit in the case of lighter oils. Improvements might also be achieved in the case of heavier oils if the number of vanes could be reduced to a sufficient extent. It is cautioned, however, that for applications in broken ice fields, a substantial reduction in the number of vanes without compensating modifications would likely result in a reduction in the very desirable inherent ice processing ability of the Lockheed unit.

6. The tests conducted indicate that at a drum rotational speed of 6 rpm, the oil recovery rate of the Lockheed unit operating in a 0.73 cm nominal thickness of oil,is optimized at a forward speed of about 0.8 fps. The resulting oil recovery rate for operation in No. 2 fuel oil is 15 gpm, while that for operation in crude oil is 11 gpm.

7. In general, at a forward speed of 0.5 fps and a 0.73 cm nominal thickness of oil, the oil recovery rate and the throughput efficiency of the Lockheed unit can be increased with an increase in the speed of drum rotation, but at some penalty in oil recovery efficiency. This penalty is insignificant in the case of the lighter oils, but quite significant in the case of a heavy crude.

8. Observations of tests conducted with the Lockheed unit revealed three possible ways in which the vanes could effect the oil recovery performance of the unit. Due to the paddle wheel effect of the vanes, there is some tendency for the unit to drive oil down into the water column. Some of this oil is likely bypassed by the unit before the oil can resurface. A second effect noticed was that the vanes are coated with oil as they enter the slick, and some of this oil is subsequently thrown off the vanes as they resurface on the downstream side of the unit. This effect was more noticeable with the heavy crude oil. Finally, periodic spillage through the back side of the unit was observed from the area between the vanes as the vanes surfaced with drum rotation.

9. Brief tests conducted at the conclusion of the planned test program in the light No. 2 fuel oil with a barrier installed aft of the Lockheed unit intended to retain any oil passed through or around the drum failed to establish that recovery on the back side of the drum occurred with a resulting increase in oil recovery rate. Qualitatively, the addition of the barrier clearly does provide for the containment of some oil which would otherwise be lost to the Lockheed device. The oil was observed to build-up within the barrier region to the point where it makes contact with the back side of the drum,at which time it is conceivable that the drum could recover oil from the barrier region. Since oil was never observed escaping from the barrier region, it is probable that recovery from the barrier region did occur, however, variations in the oil recovery rates measured were so great as to negate the possibility of quantitatively verifying this type of recovery.

10. Tests of the Marco oil spill recovery device in conjunction with a static ice processor, a freewheeling ice processor, and several variations of an active ice processor, indicate that all three types of processors have promise of improving the oil recovery performance of the Marco unit when operated in broken ice fields. In comparison to the unmodified device, improvements of as much as 59% were measured in oil recovery rate, 230% in oil recovery efficiency, and 56% in throughput efficiency. It should be noted that the use of external processors is not required with the Lockheed unit since its rotational motion inherently processes the broken ice as it is encountered.

11. The success of the ice processing devices developed for use with the Marco unit indicates that with the development of effective equipment for processing the ice around an oil recovery device, and separating the oil from the broken ice field, the selection of an oil recovery device can be made on the basis of open water performance, assuming that proper provision has been made for the remaining harsh environmental conditions.

12. Tests conducted with an OSI Skimmer and a JBF DIP indicated that both units are not well adapted to applications in broken ice fields in their off-the-shelf condition. Both units could, however, be adapted for successful operations in broken ice fields through the addition of ice processing equipment in a manner similar to that employed with the Marco unit.

13. Tests conducted with an Oil Mop unit in ice-infested waters indicated that the unit has definite promise in applications involving heavier oils. The unit had no difficulty in operating

in the broken ice field and achieved good oil recovery performance in crude oil. However, the oil recovery performance fell off drastically in the light No. 2 fuel oil.

RECOMMENDATIONS

While the test program described herein, and the Phase I program which preceeded it, have substantially increased the fund of knowledge available upon which to approach the recovery of oil spilled in ice-infested waters, the fact remains that the equipment tested in these programs has a range of applicability limited to broken ice pieces of moderate ice piece size. The geographic areas of applicability for such equipment include the northern rivers, lakes, and coastal areas of the contiguous 48 states, and regions of Alaska where ice conditions are moderate. The ultimate oil spill recovery device suitable for general use throughout the high Arctic must be capable of recovering oil spilled on, under, or trapped within solid first year ice, solid multiyear ice, broken ice cover of substantial ice piece size, and perhaps even oil trapped within pressure ridges. The gap between this ultimate system and present day capability is substantial, and an orderly development of increasingly more capable systems and equipment must be planned so that the required capability will be available in a timely manner. With the development of the Arctic's petroleum resources progressing at a steady rate, an analysis directed toward the definition of the time-phased capabilities required from oil spill recovery equipment designed for use in cold regions should be undertaken immediately. The results of such an analysis will serve to guide future programs through a gradual advancement in requirements and corresponding capability, finally culminating in the ultimate oil spill recovery device for general application throughout the high Arctic.

APPENDIX A

DESCRIPTIONS OF OIL RECOVERY EQUIPMENT TESTED

Lockheed Unit

The Lockheed oil recovery device tested in this program was the Lockheed Clean Sweep Model R2003, a nominal 4 foot diameter by 7 foot wide disc drum unit. Figure A-1 is a sketch showing the general principle of operation of the Lockheed Clean Sweep oil recovery device. The Lockheed device operates on the principle that oil adheres to any surface which it wets. A series of relatively closely spaced discs are immersed to approximately one third of their diameter in the oil covered water and rotated. As any point on the disc enters the oil, oil adheres to the disc and remains there during the submerged portion of the rotation. When that point continues rotation such that it surfaces on the upward side of its travel, the oil remains on the surface of the disc while water runs off. A collecting trough is positioned centrally in the series of discs and serves as the axle of the unit. A series of stationary wipers are located vertically above the collecting trough. Oil is wiped from the discs and flows into the trough by the force of gravity. A conveyor screw located in the trough then moves the recovered oil from the central trough to the sump. The discs are mounted parallel to one another and supported at their perimeter by transverse vanes which overlap as shown in Figure A-1. These vanes tend to act in a paddlewheel manner, creating a current which causes the oily water to flow into the drum between the parallel discs.

The Lockheed oil recovery device tested was constructed of parallel aluminum discs with twenty-four overlapping longitudinal vanes. The vanes are slotted on each end to fit into the receiving slots on the discs. Each vane is bent through a shallow angle along its length, and is flattened slightly for installation in the receiving slots. The vanes are retained in place by spring action. They act as support for the central discs and transmit the rotational force from the end discs, which are attached to the main drum bearings. The standard unit is supplied with two adjacent vanes made from thinner material in order that they may be more easily removed for access to the interior of the drum. For operations in broken ice cover in this test program, the two lightweight vanes were removed and replaced with vanes of the standard, heavier thickness. The wiper blades which ride on both surfaces of each disc are manufactured from a plastic material held in place by a stainless steel spring. The principal dimensions

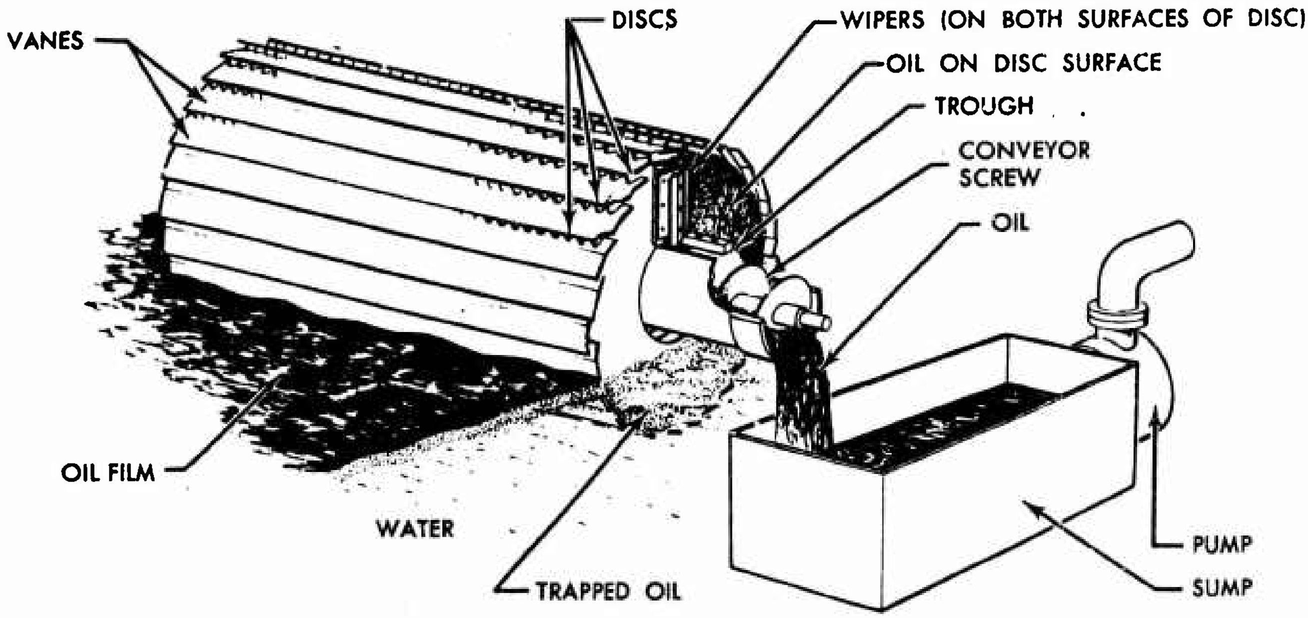


FIGURE A-1. SKETCH SHOWING THE OPERATING PRINCIPLE OF THE LOCKHEED CLEAN SWEEP OIL RECOVERY DEVICE.

of the Lockheed R2003 unit tested, bearing Configuration Number P/N5517925-503 and Serial Number 3-0643, are shown in Figure A-2.

Marco Device

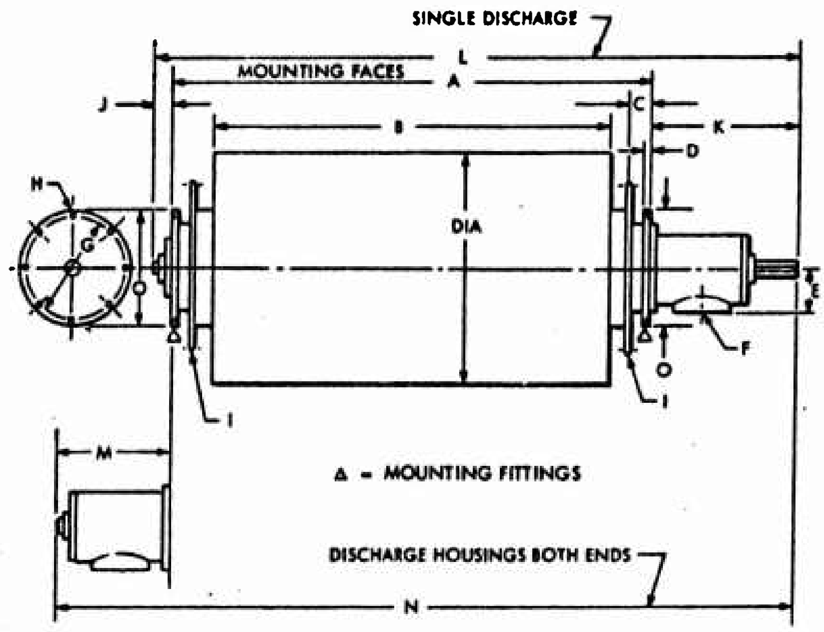
The Marco unit tested in this program was the Marco Pollution Control Class I Oil Recovery System, an oleophilic belt device having a nominal belt width of one foot. Figure A-3 is a sketch showing the major features of the device tested and its principle of operation. Basically, the principle of operation consists of absorbing oil in a fibrous belt and then removing the oil by squeezing or wringing it out of the belt. The Filterbelt material is a synthetic foam material having a stranded open-cell construction which permits water to flow through the open cells of the material while oil is trapped within the cells. In operation, oil is lifted from the surface of the water by the continuous conveyor of Filterbelt material. The entrained oil is wrung from the Filterbelt by a pneumatically tensioned squeeze roller into a reclaimed oil sump. A hydraulically driven propeller is located at the base of the Filterbelt boom to create a current and draw oil and water through the belt. Constant tension is maintained on the Filterbelt by a pneumatic cylinder arrangement.

The portable power unit supplied with the Marco Class I Oil Recovery System was used to power both the Marco unit and the Lockheed Clean Sweep unit in this test program. The major components of this portable power system are also shown in Figure A-3. The unit consists of a 6.3 horsepower air cooled diesel engine driving a hydraulic pump and an air compressor.

The Marco Class I System is a relatively portable unit in that the boom assembly disconnects from the sump housing, allowing independent movement of the two major components. The primary construction material is aluminum.

OSI Skimmer

The OSI Skimmer tested in this test program was the ORS-125, an oil recovery system designed for a nominal oil recovery rate of 125 gpm by Ocean Systems, Inc. The operation of the OSI Skimmer is based on the principle that oil thickens in front of a physical barrier moving relative to the water surface as shown in Figure A-4. The forward motion of the recovery system, as well as the thickening of the slick in front of the device, causes a dynamic head of oil to be built-up ahead of the device. An opening, or weir, installed near the oil surface uses this dynamic head to cause oil to flow



LETTER		LETTER	
A	91.5 IN.	K	14.1 IN.
B	85.5 IN.	L	107.6 IN.
C	1.3 IN.	M	11.2 IN.
D	0.5 IN.	N	116.8 IN.
E	6.7 IN.	O	17.0 IN.
F	5" NPT CPLG.	WEIGHT	1,350 LB

FIGURE A-2. PRINCIPLE DIMENSIONS OF THE LOCKHEED CLEAN SWEEP R2003 TESTED.

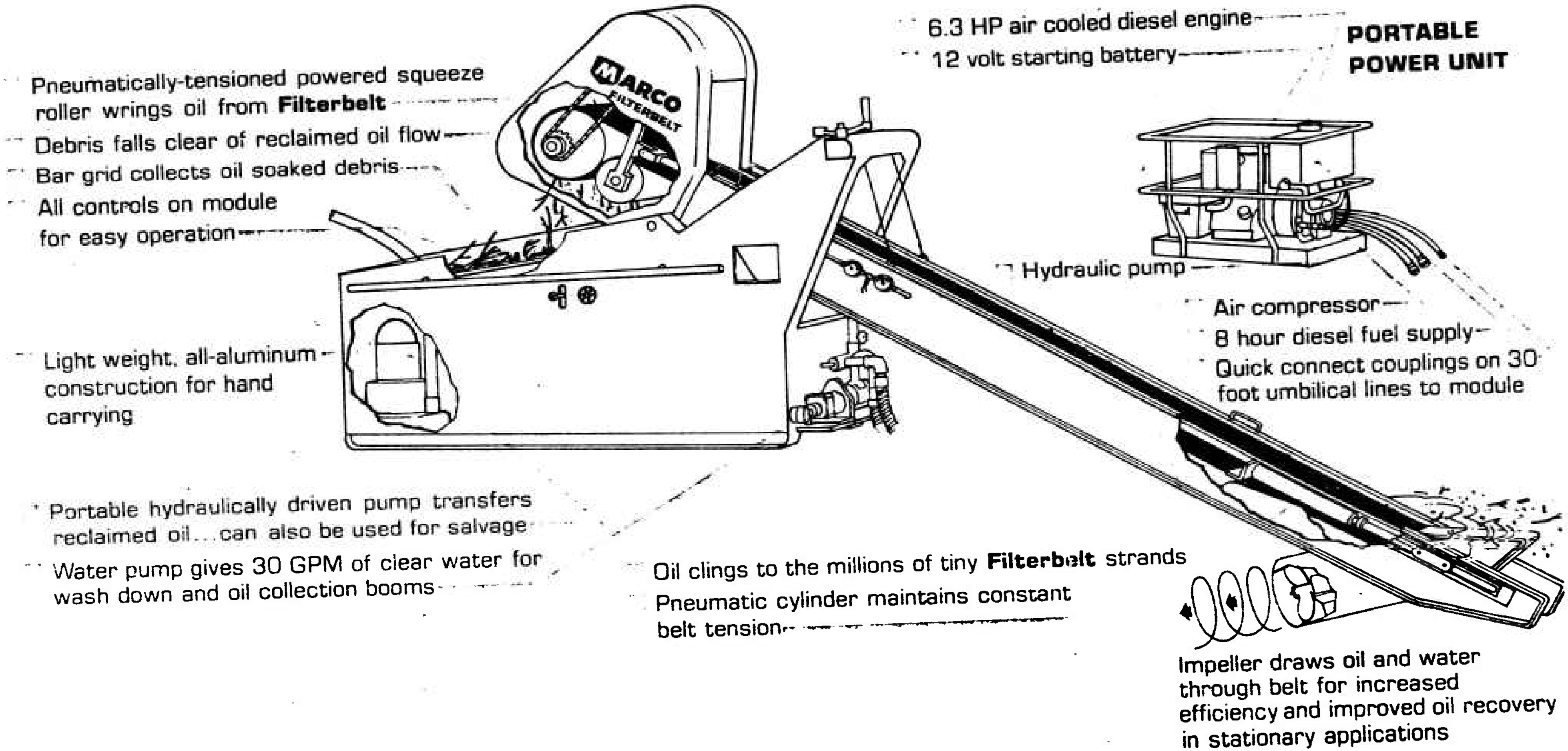


FIGURE A-3. SKETCH SHOWING THE MAJOR FEATURES AND THE PRINCIPLE OF OPERATION OF THE MARCO CLASS I OIL RECOVERY DEVICE.

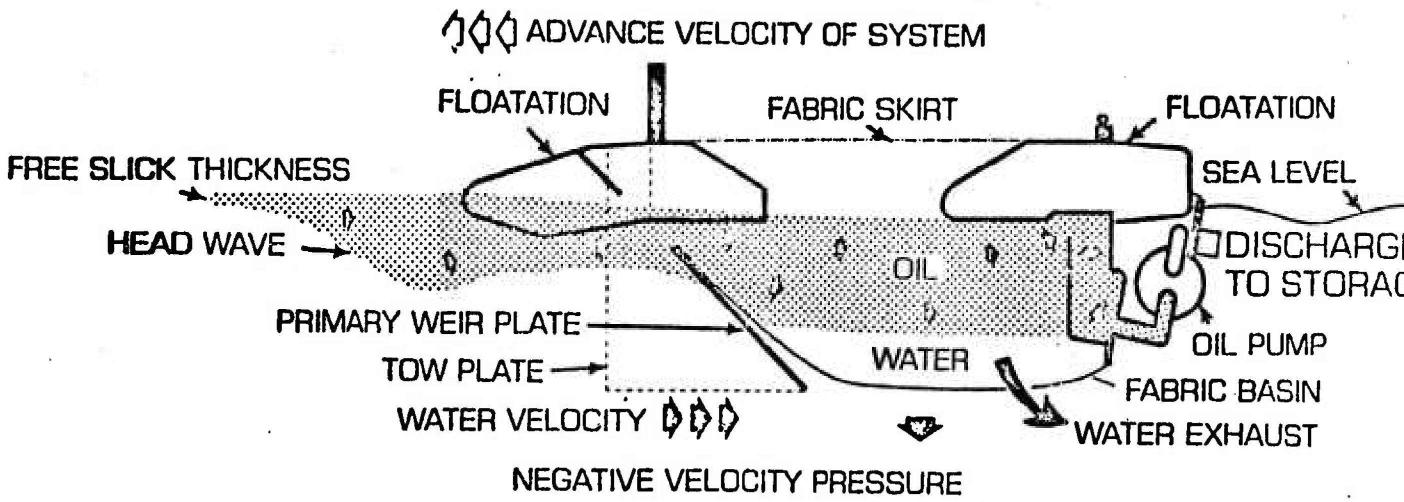


FIGURE A-4. SKETCH SHOWING THE PRINCIPLE OF OPERATION FOR THE OSI SKIMMER.

through the weir into a recovery basin. In the recovery basin, the oil thickens further because of the accelerated flow beneath the basin which causes negative velocity pressures along the streamlined bottom of the basin. From this thickened oil pool the oil flows over a secondary weir from which it is pumped to a storage location. The unit is intended to pass most free water carried over the primary weir out the basin bottom through transverse slots. The oil at the pump suction has little entrained water under most conditions. The system requires some relative motion or current between the recovery system and the slick for efficient operation. The optimum range of tow speeds, or current speeds, for the system is 0.7 to 1.0 knots. The pumping system installed in the device is a double diaphragm air operated pump having power input requirements of 60 SCFM at 100 psi. Figure A-5 is a sketch identifying the major components of the OSI Skimmer.

JBF DIP

The oil recovery device tested in this program designated as the JBF DIP is a dynamic inclined plane (DIP) recovery system manufactured by JBF Scientific Corporation. The operating principal of this oil recovery device is sketched in Figure A-6. The JBF DIP collects oil by forcing it under the surface of the water with a moving belt. Oil follows the surface of this moving inclined plane to a collection well beneath the unit. Buoyant forces then cause the oil to naturally separate in the well where it forms a deep pocket of oil. Relatively water-free oil is then pumped from the top of the well to the storage container. The moving plane is made of a heavy duty conveyor belt material. The specific unit tested in this program was the DIP 1001 Oil Skimmer, supplied in a trailer mounted package as the DIP 1002 System. In addition to the inverted collection belt comprising the moving plane, the oil skimmer has twin propellers driven by pneumatic motors, and a pneumatically driven diaphragm pump to transfer the collected oil to the storage tank. Figure A-7 is a sketch of the DIP 1002 trailer mounted system which includes a trailer, a hoist and crane, an air compressor, the skimmer itself, and various accessories. The system characteristics are also identified in Figure A-7.

Oil Mop

The Oil Mop unit tested in this program was the Mark II-4EP unit, incorporating an electric drive and a pump, manufactured by Oil Mop, Incorporated. As shown in Figure A-8, the Oil Mop recovery process consists of three basic elements, a rope mop which absorbs oil and rejects water, a method to expose the mop to floating oil, and a method to clean the mop of the absorbed oil. Oil Mop's rope is a configuration of plastic fibers woven into a plastic rope. The

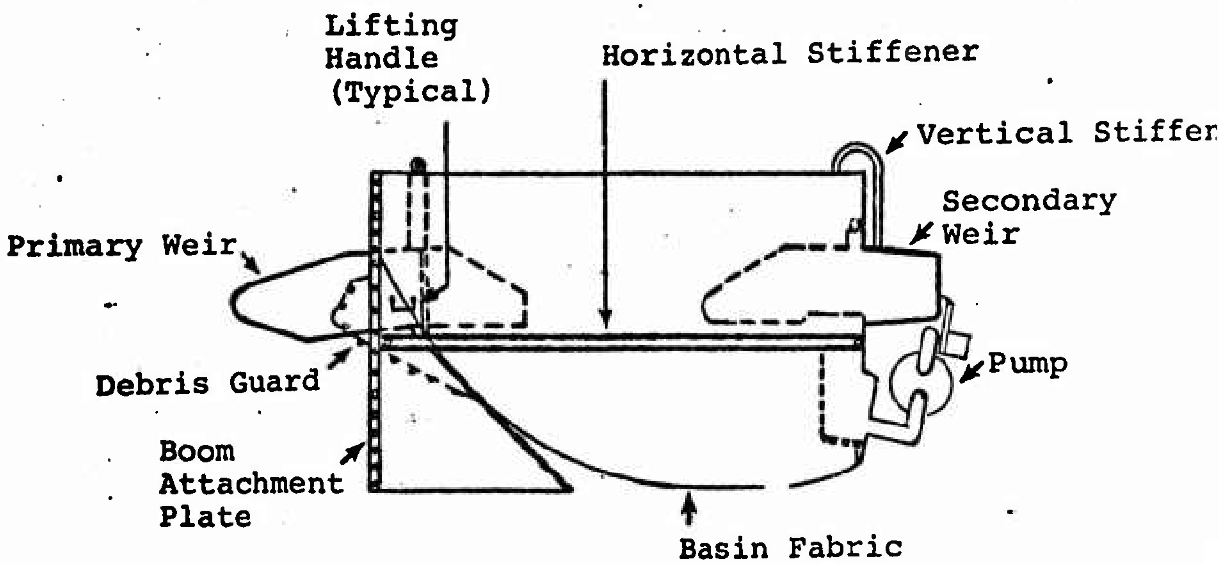


FIGURE A-5. SKETCH IDENTIFYING MAJOR COMPONENTS OF THE OSI SKIMMER.

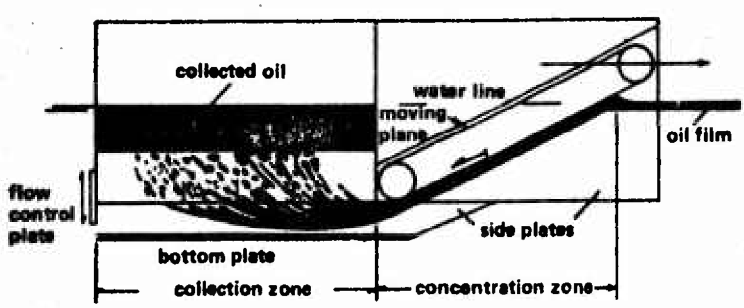
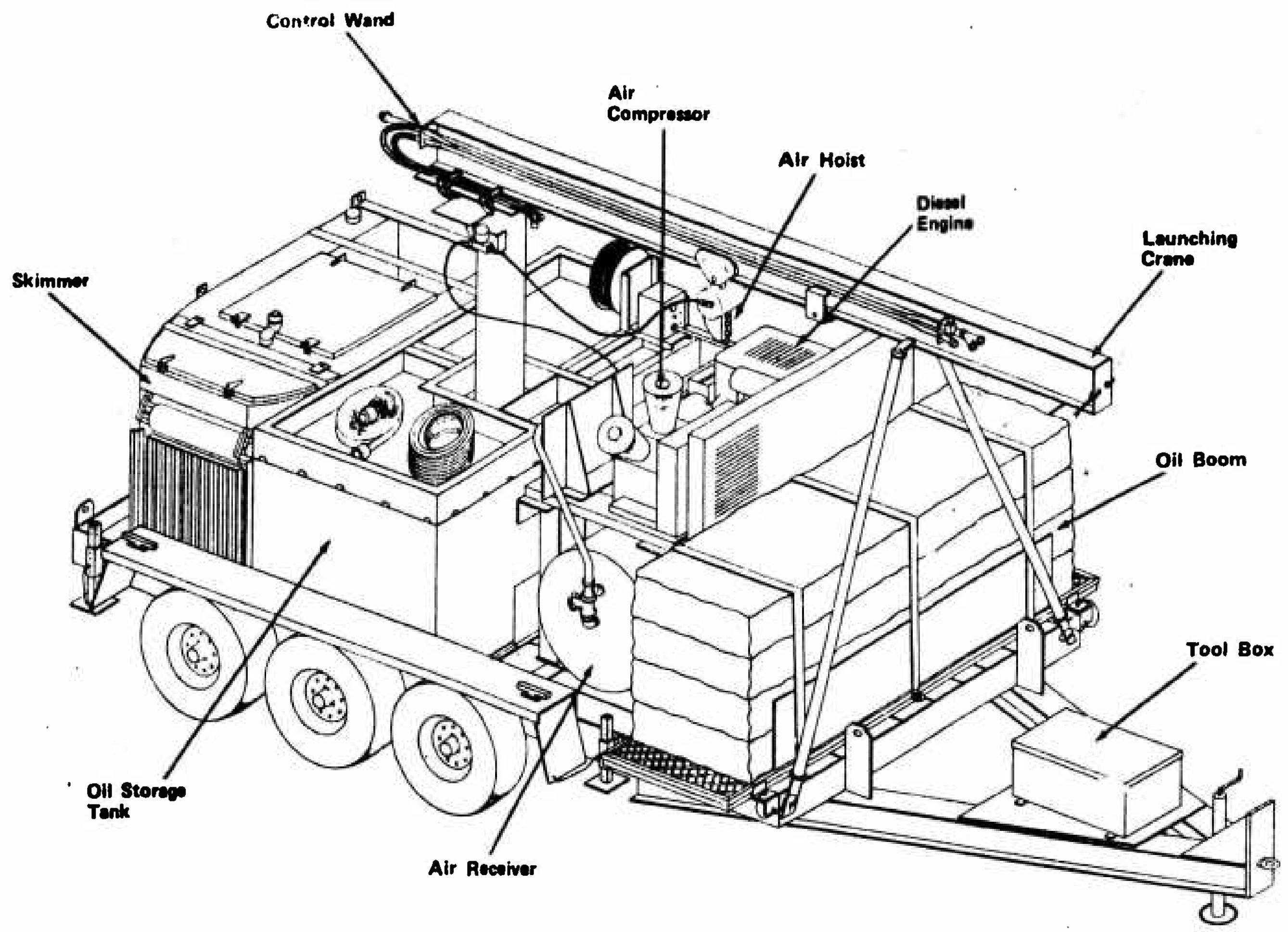


FIGURE A-6. SKETCH SHOWING THE OPERATING PRINCIPLE OF THE JBF DIP.



SYSTEM CHARACTERISTICS

Trailer

Capacity	18,000 lbs
Length	21'
Beam	8'
Height	11'
Oil Storage	400 U.S. Gallons

Hoist and Crane

Capacity	1000 lbs
Reach	12'
Height	8'
Rotation	360

Air Compressor

Rating	100 psi 60 scfm
Receiver	120 gal
Drive	25 HP Diesel

Accessories

Oil Boom	200'
Air Hose	200'
Oil Hose	200'
Vapor Detector	
Tool Box	
Oil/Water Interface Detector	

Skimmer

Displacement	600 lbs
Length	6'
Height	3'
Beam	3'6"
Control Wand	22'
Pump	50 gpm

Performance (10 mm slick)

Maneuvering	23 GPM @ 0.5 knots
Stationary Link (25' Aperture)	56 GPM @ 0.1 knots
Wave Height	1 foot

FIGURE A-7. SKETCH OF THE DIP 1002 TRAILER MOUNTED SYSTEM.

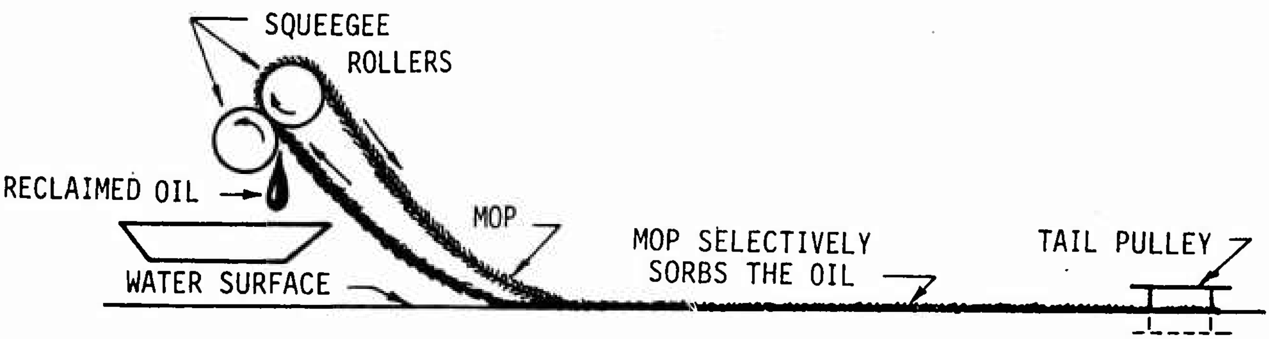


FIGURE A-8. SKETCH SHOWING THE OPERATING PRINCIPLE OF THE OIL MOP OIL RECOVERY DEVICE.

resulting thick nap of the mop is oleophilic and hydrophobic, that is, it attracts oil and resists water. The Oil Mop rope is threaded through a mop engine which wrings oil from the saturated mop. Opposite the mop engine, a tail pulley or idler pulley allows the mop to form a continuous loop on the surface of the oil slick. Oil Mop manufactures ropes which range in diameter from 4 to 36 inches. A 4 inch diameter rope was used in this test program. Figure A-9 shows the general configuration, the overall dimensions, and the rope threading details for the Oil Mop unit tested. The rather complex threading system is required to obtain additional wrings when working with long lengths of rope, or large diameter rope, or when the ropes are heavily laden with oil. The multiple wringing system increases the grip of the Oil Mop engine on the rope. The system tested was powered by a 0.5 horsepower single phase electric motor and had a dry weight of 360 pounds.

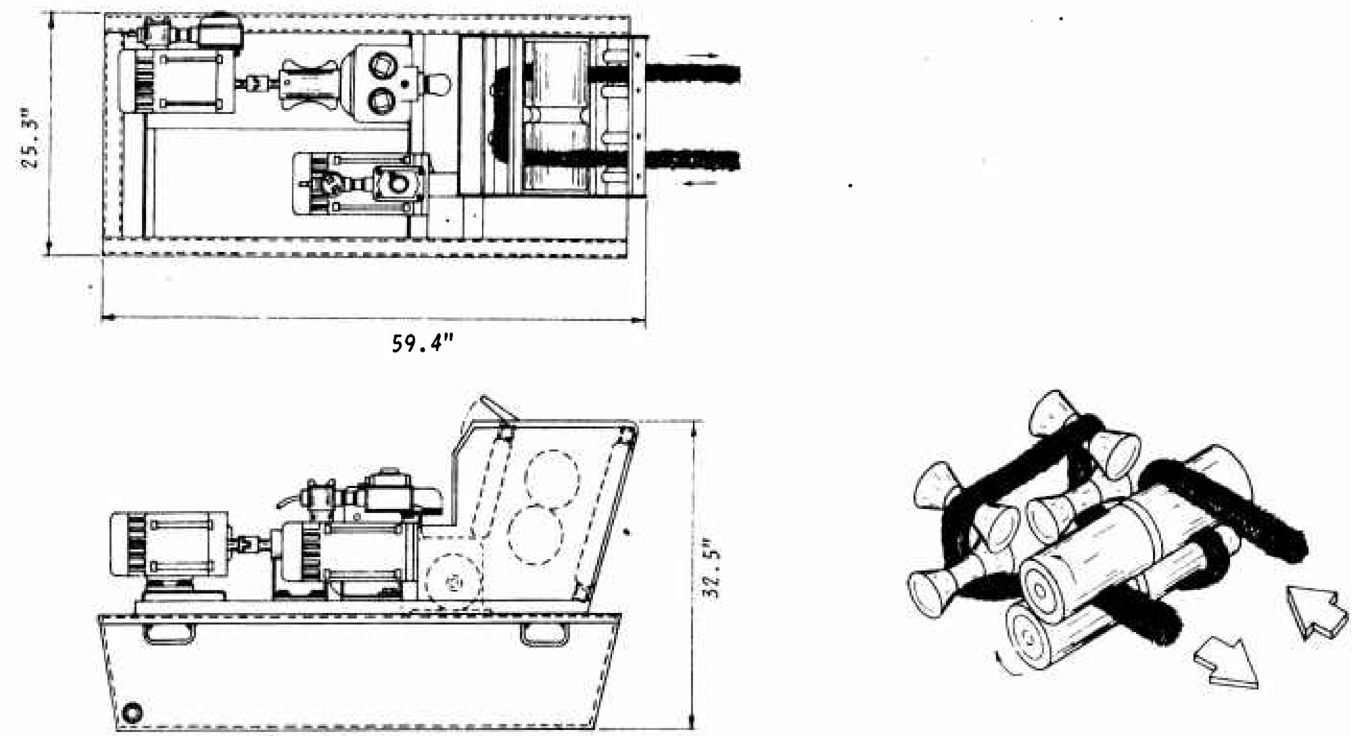


FIGURE A-9. GENERAL CONFIGURATION, OVERALL DIMENSIONS AND ROPE THREADING DETAILS FOR THE OIL MOP UNIT TESTED.

APPENDIX B

MEASUREMENT INSTRUMENTS AND TECHNIQUES

Throughout the course of this test program, physical properties of the oil in the basin were measured at the start of each test day, and the physical properties of the oil recovered during a test were measured after each test. These oil physical properties included the specific gravity, viscosity, surface tension, temperature and emulsification.

ASTM approved hydrometers meeting ASTM specification E100-66 were used to measure specific gravity. Pre-test oil samples were taken directly from the surface of the model basin in a graduated cylinder held at the same temperature as the oil. Several samples were taken at different points along the basin and the average value reported. For the post-test measurement, oil was taken from the recovered oil/water/ice mixture after the oil and water had been allowed to settle out. All measurements were taken in a cold room immediately adjacent to the model basin which was held at the same temperature as the model basin. The appropriate hydrometer was lowered into the sample and allowed to settle. After temperature equilibrium had been reached, the hydrometer scale was read and the temperature of the sample recorded. The procedures used are in accord with ASTM specification D287-67.

A model LVT Brookfield Viscometer was used to measure apparent viscosity. The instrument was calibrated prior to the test program and the calibration was checked throughout the program. The viscosity measured by this instrument is expressed in the units of centipoise, where a poise has the units of grams per centimeter per second. Pre-test viscosity samples were taken directly from the surface of the model basin in a beaker held at the same temperature as the oil. The post-test sample was taken from the recovered oil after the oil and water had settled. Again, multiple samples were taken and the average measurement reported. The Brookfield Viscometer rotates a cylinder or disc in the fluid being measured and relates the measured torque to the viscosity of the fluid. This torque measurement is accomplished by driving the immersed element, called a "spindle", through a beryllium copper spring. The degree to which the spring is wound indicated by the position of the pointer on the viscometer's dial, is proportional to the viscosity of the fluid for any given speed and spindle. The procedures used in measuring viscosity were in accordance with the ASTM specification D2983-72.

Measurements of surface tension were made with a Fisher Surface Tensiometer, Model No. 20. The sampling techniques were similar to those used for the specific gravity and viscosity tests with all measurements taken in the cold room to maintain the proper temperature. The Fisher Model No. 20, essentially a torsion-type balance, is the type of instrument currently specified in ASTM specifications B-971 and D-1331. In this device, a platinum iridium ring of precisely known dimensions is suspended from a counter-balanced lever arm. The arm is held in a horizontal position by torsion applied to a taught stainless steel wire to which it is clamped. Increasing the torsion in the wire raises the arm, and the ring, which carries with it a film of the liquid in which it has been immersed. The force necessary to pull the test ring free from the surface film is shown on the dial of the instrument and is then converted to provide a measure of the true surface tension.

Emulsification measurements were made by the centrifuge technique as specified in ASTM specifications D96-68 and D1796-68. Again, several samples were taken to ensure a representative value. Centrifuge tubes were filled to the 50 ml mark with benzene conforming to ASTM specification D836. The well shaken sample was then added to the centrifuge tube until the total volume was 100 ml. The tubes were stoppered and shaken vigorously until the contents were mixed thoroughly. The tubes were then immersed for 10 minutes in a bath maintained at 120 ±2°F. The tubes were then shaken again, placed in a centrifuge, and whirled at a force of 800 rcf at the tips of the tubes for ten minutes. The final volume of water was then recorded, and the percentage of water or oil was determined. Values as low as 0.5 percent could be measured with this technique.

All temperatures reported were measured with ASTM approved thermometers accurate to 0.01°C.

REFERENCES

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2. "Test Plan - Phase II Full Size Tests of Oil Recovery Devices In An Oil/Ice/Water Controlled Environment Test Facility", submitted to the U.S. Coast Guard by ARCTEC, Incorporated, September 19, 1975.